1957

An investigation of the buckling caused by compressive forces existing in a thin elastic sheet, with a hole in the center, subject to uniform tension at two edges.

Danis, John F.

Monterey, California: Naval Postgraduate School, 1957.

BUCKLING NEAR A HOLE CENTERED IN A TENSION FIELD

JOHN F. DANIS

Letter on cover:

BUCKLING NEAR A HOLE CENTERED
IN A TENSION FIELD

John F. Danis

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BUCKLING NEAR A HOLE
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John F. Danis

AN INVESTIGATION OF THE BUCKLING

CAUSED BY COMPRESSIVE FORCES

EXISTING IN A THIN ELASTIC SHEET,

WITH A HOLE IN THE CENTER, SUBJECT

TO UNIFORM TENSION AT TWO EDGES

by

John F. Danis

Lieutenant, United States Navy

Submitted in partial fulfillment of
the requirements for the degree of

MASTER OF SCIENCE
IN
MECHANICAL ENGINEERING

United States Naval Postgraduate School
Monterey, California

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from the

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ABSTRACT

In a thin elastic sheet, with a hole in the center, subject to uniform tension on two opposite edges, a small area at the rim of the hole along the diameter of the hole parallel to the tension is in compression circumferentially.

This compression can cause buckling in this area. Such buckling may occur before the sheet yields at its point of maximum stress. Using Southwell's method of determining the critical buckling load, the relationship

$$\sigma_{cr} = KE\left(\frac{t}{d}\right)^2$$

is established, where σ_{cr} is the critical value of the uniaxial tension at a distance from the hole; d is the diameter of the hole; t is the thickness of the plate; E the (Young's) modulus of elasticity of the material; and K is an experimentally determined function of the ratio d/b of hole diameter to plate width.

This investigation was conducted at the United States Naval Postgraduate School, Monterey, California, in early 1957, by John F. Danis, Lieutenant, United States Navy, in partial fulfillment of the requirements for the degree of Master of Science in Mechanical Engineering.

The writer wishes to express his appreciation to Professors R. E. Newton and J. E. Brock, whose ideas, advice, and assistance made this paper possible.

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LIST OF ILLUSTRATIONS

SYMBOLS

a -- Radius of Hole

a' -- Length of Sheet

b -- Width of Sheet

b' -- Constant Associated with Initial Curvature

d -- Diameter of Hole

h -- Thickness of Sheet (also designated t.)

k_y -- Expression for Curvature

l -- Length Measurement

t -- Thickness of Sheet

$w(x, y;P)$ - Primary Deflection due to Load

$w(x, y;0)$ - Initial Primary Deflection with no Load

x -- The Axis parallel to Applied Tension

y -- The Axis perpendicular to Applied Tension

A_i -- Coefficients which characterize Initial Deflection

B -- Strain gage reading for gages used to measure strain caused by change of radius of curvature at points of buckling.

B_o -- Initial Strain Gage Reading of B

B -- Difference in above. $(B - B_o)$

D -- Rigidity Function = $\dfrac{Eh^3}{12\ (1 - \nu^2)}$

D_1 -- Function of Initial Curvature = $B_o - b'$

E -- Modulus of Elasticity

I -- Moment of Inertia

EI -- Bending Modulus

K -- A function of d/b = $\dfrac{\sigma_{cr}}{E} \cdot \left(\dfrac{d}{t}\right)^2$

P -- Applied Load

P_i -- Critical Load for all Modes of Buckling

P_1 -- Critical Load for Primary Mode of Buckling

P_{cr} -- Critical Load as Determined by Experimentation

$W_n(x, y; P)$ -- Total Deflection due to all Modes of Buckling

$W_n(x, y; 0)$ -- Initial Deflection due to all Modes of Buckling at No Load

β -- Modulus of Elastic Support

Θ -- Angle Measurement .

$\Psi(x,y)$ -- Normal Function

τ -- Shearing Stress

σ -- Normal Stress

σ_{cr} -- Critical Buckling Stress = $\frac{P_{cr}}{bt}$

ν -- Poisson's Ratio

1. Introduction.

GENERAL DISCUSSION OF THE PHENOMENA AND THE EFFECTS

The problem of determining the stresses in an elastic plate under tension when the material is pierced by a circular hole is one of both theoretical interest and practical importance. Provided that the plate may be regarded as infinitely extended in two dimensions, the solution for a single hole is easily found and is well known. The presence of the hole leads to the occurrence of stresses equal to three times the tension at infinity, these maximum stresses occurring at the edge of the hole and on the diameter perpendicular to the direction of the applied tension. At the edge of the hole and on the diameter parallel to the direction of the applied tension a circumferential compressive stress occurs equal to the tension applied at infinity. For sheets of finite width, with a hole diameter equal to four-tenths of the width of the sheet, it has been found that this maximum stress is 3.74 times the applied stress, while the compressive stress has been found to be -1.44 times the applied stress. With a hole diameter equal to one-tenth of the width of the sheet, the maximum stress has been found to be 3.03 times the applied stress, while the compressive stress has been found to be -1.03 times the applied stress. (5)*

The presence of compressive stresses in a thin elastic sheet leads to the question of the condition under which buckling may occur. A search of the literature indicated that this question has not been investigated previously. (4) Accordingly, the investigation reported herein was undertaken for the purpose of experimentally determining the

* Numbers in parentheses refer to bibliographical references found on page 36.

conditions under which buckling would take place in such an elastic sheet pierced in the center by a circular hole and subjected to uniaxial tension.

In this analysis, it was assumed that Southwell's method of determining critical buckling load would be valid for all diameters of holes and all plate thicknesses. This assumption proved to be not altogether valid, but sufficient valid data were obtained to give legitimate results. It was necessary to obtain sufficient data on the buckling deflection to determine the critical buckling load, prior to yielding of the sheet at the point of maximum stress.

With this value of critical buckling load, the buckling stress was calculated; and, using the relationship,

$$\frac{\sigma_{cr}}{E} = K_{(d/b)} \left(\frac{t}{d}\right)^2$$

where $K_{(d/b)}$ is a function of hole diameter to plate width, K was evaluated for all sheets. This final result was plotted with K versus d/b.

2. Theoretical Analysis.

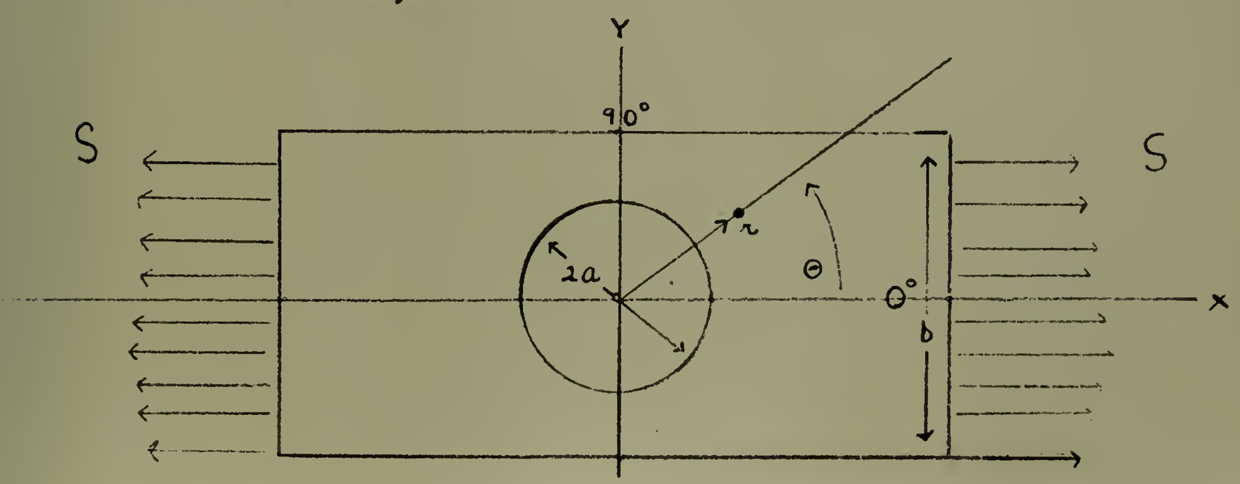


Figure 1

Figure 1 represents a plate submitted to a uniform tension of magnitude S in the x direction. If a small circular hole is made in the center of the plate, the stress distribution in the vicinity of the hole will be changed. For such a configuration with $b \gg 2a$, the stresses produced are: (11)

$$\sigma_r = \frac{S}{2}\left(1 - \frac{a^2}{r^2}\right) + \frac{S}{2}\left(1 + \frac{3a^4}{r^4} - \frac{4a^2}{r^2}\right)\cos 2\theta \qquad \text{Equation 1}$$

$$\sigma_\theta = \frac{S}{2}\left(1 + \frac{a^2}{r^2}\right) - \frac{S}{2}\left(1 + \frac{3a^4}{r^4}\right)\cos 2\theta \qquad \text{Equation 2}$$

$$\tau_{r\theta} = -\frac{S}{2}\left(1 - \frac{3a^4}{r^4} + \frac{2a^2}{r^2}\right)\sin 2\theta \qquad \text{Equation 3}$$

Then at the edge of the hole $\sigma_r = \tau_{r\theta} = 0$ and $\sigma_\theta = S - 2S\cos 2\theta$. Thus, σ_θ is greatest when $\theta = \frac{\pi}{2}$ or $\theta = \frac{3\pi}{2}$, and is equal to 3S. This is the maximum tensile stress and is three times the uniform stress S applied at the ends of the plate. At the points where θ is equal to π and 0 we find σ_θ is equal to -S, so that there is a compression stress in the tangential direction at these points.

If the width of the plate is not less than five diameters of the hole, the error of the solution of the above equation for calculating σ_θ (max) does not exceed eleven percent. (5)

The stress at these points for sheets of finite width with holes of known diameters are tabulated in Table 1. By inspection of this table it would appear that the stress applied at the edge of the plate would have to be less in the plates with the larger holes to create the critical buckling stress at the edge of the hole.

RATIO OF THE STRESS AT THE RIM

OF THE HOLE TO THE STRESS APPLIED AT THE EDGE OF THE SHEET,

(Determined by Photoelastic Methods) (5)

d/b = Ratio of diameter of hole to sheet width

θ = Angle measured counterclockwise from x axis

θ \ d/b	0	.1	.2	.3	.4	.5
0°	-1.00	-1.03	-1.11	-1.26	-1.44	-1.58
15°	- .73	- .74	- .82	- .95	-1.12	-1.32
30°	0.00	- .01	- .06	- .15	- .30	- .51
45°	1.00	1.00	1.00	.98	.91	.77
60°	2.00	2.01	2.07	2.15	2.25	2.32
75°	2.73	2.74	2.85	3.03	3.32	3.72
90°	3.00	3.03	3.14	3.36	3.74	4.32

TABLE 1

In order to assist in understanding the compressive stress distribution around the hole, it is interesting to examine the stresses in the "Y" direction.

Figure 2 illustrates a section of the plate near the rim of the hole with all stress vectors shown.

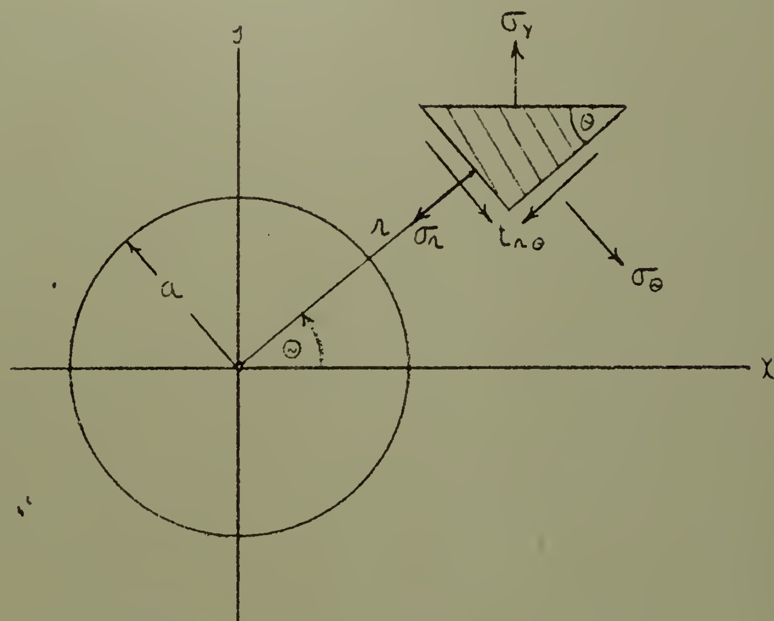


Figure 2

Then

$$\Sigma F_y = \sigma_y - \sigma_r \sin^2\theta - \sigma_\theta \cos^2\theta - 2t_{r\theta} \sin\theta \cos\theta = 0$$

$$\sigma_y = \sigma_r \sin^2\theta + \sigma_\theta \cos^2\theta + 2t_r \sin\theta \cos\theta \qquad \text{Equation 4}$$

Then combining Equations 1, 2, 3 and 4, it can be shown that

$$\sigma_y = \frac{S}{2}\left[-\frac{a^2}{r^2}\cos 2\theta - \left(\frac{3a^4}{r^4} - \frac{2a^2}{r^2}\right)\cos 4\theta\right]$$

Equation 5

The area around the hole in compression as determined from Equation 5 is illustrated in Figure 3. The heavy line is the boundary at which $\sigma_y = 0$. The dotted line encloses the area within which $\sigma_y = -S/10$ to $\sigma_y = -S$.

In Figure 4 the boundary for $\sigma_y = -S/10$ is shown, with the boundary for $\sigma_y = -S/2$ shown by a dotted line.

From Figures 3 and 4 it can be readily seen that although a negative value of σ_y occurs in a large area in the sheet, its magnitude attenuates quite rapidly with distance from the rim of the hole.

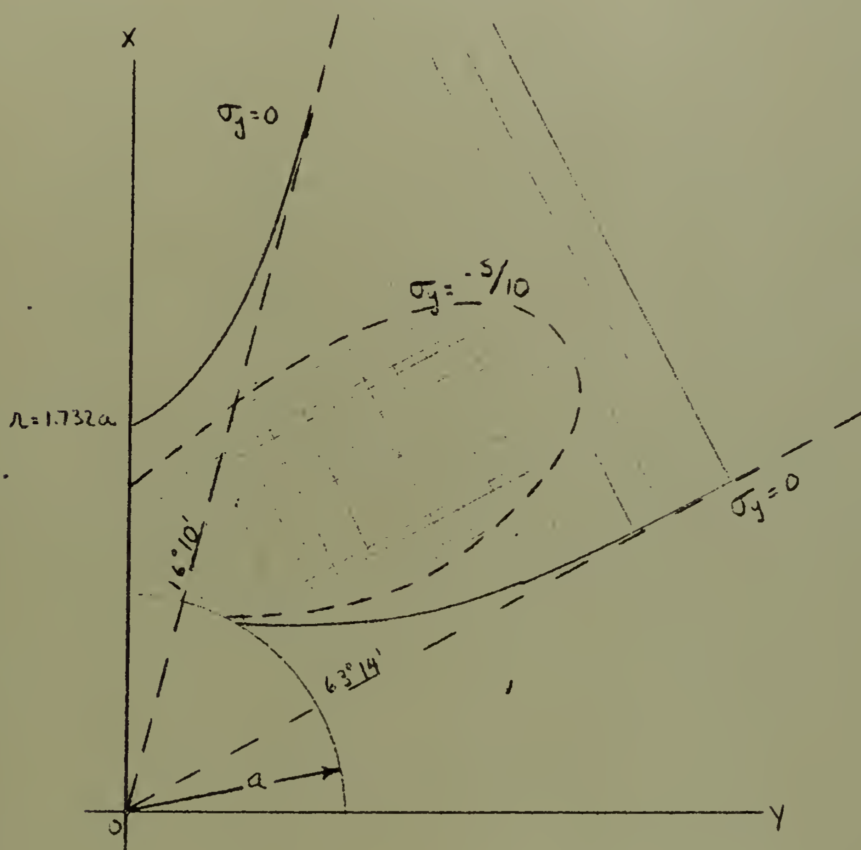
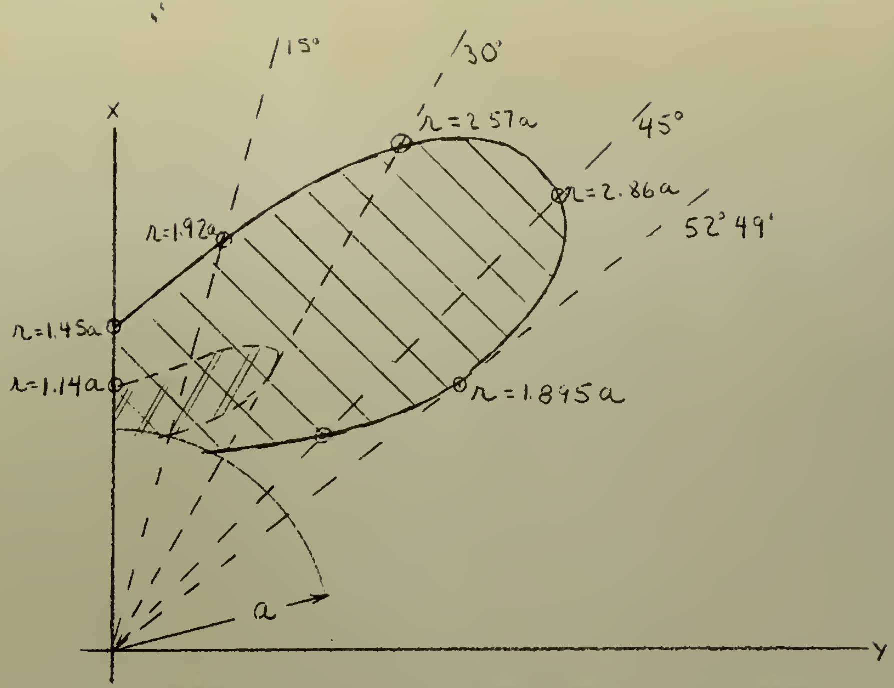


Diagram showing area surrounding hole
The single cross-hatched area is in compression.
The double cross-hatched area is under compressive stress greater than or equal to $-\frac{S}{10}$.

Figure 3



Single cross-hatched area shows area in compression with σ_y = -S/10.

Double cross-hatched area shows area in compression with σ_y = -S/2.

Figure 4

We will leave this area of investigation to examine the theory of buckling of thin plates. For a uniformly compressed rectangular plate, simply supported along two opposite sides perpendicular to the direction of compression, and having one side simply supported and the other side free,

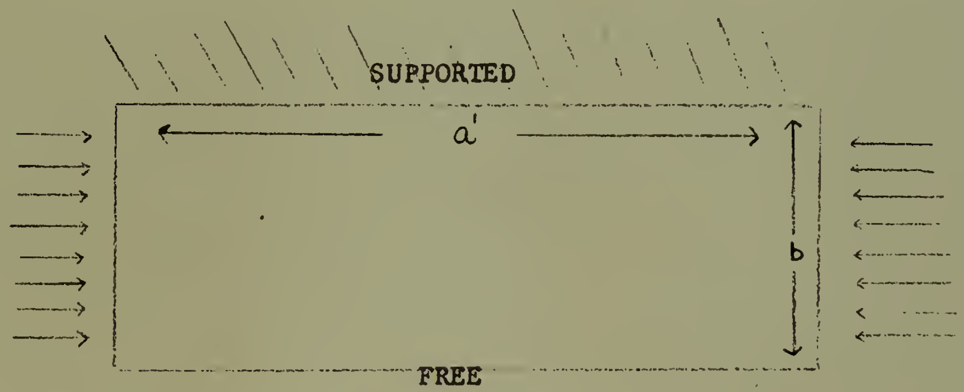


Figure 5

it has been shown that: (14) ~~(4)~~

$$\sigma_{x\,(CR)} = K \frac{\pi^2 D}{b^2 h}$$ Equation 6

where $\sigma_{x\,(cr)}$ is the stress in the x direction which will cause buckling.

$D = \dfrac{E\,h^3}{12\,(1 - \nu^2)}$, b = width, h = thickness, K is a function of a'/b.

E is the Modulus of Elasticity, and ν is Poissons ratio (the ratio of lateral unit deformation to linear unit deformation within the elastic limit). This means that

$$K_{(a'/b)} = \frac{b^2\,h\,\sigma cr}{\dfrac{\pi^2\,E\,(h^3)}{12\,(1-\nu^2)}},$$

$$K\left[\pi^2\,12\,(1-\nu^2)\right] = \frac{\sigma cr}{E}\;\frac{(b^2)}{(h^2)}$$

or

$$K' = \frac{\sigma cr}{E}\;\frac{b^2}{h^2} \qquad \text{Equation 7}$$

Now, if the area above the hole is considered a thin plate with compressive stresses in it, it is obvious that the larger the diameter of the hole the larger "a'" and "b" become. This analogy continues in the "supported" edge of Timoshenko's thin plate theory. Since the compressive force dissipates rapidly in the distance from the rim of the hole and the compressed area above the hole, the surrounding tensile stress provides a supporting force 90° to the compressive force, which, in effect, forms a supporting edge. See Figure 6 following.

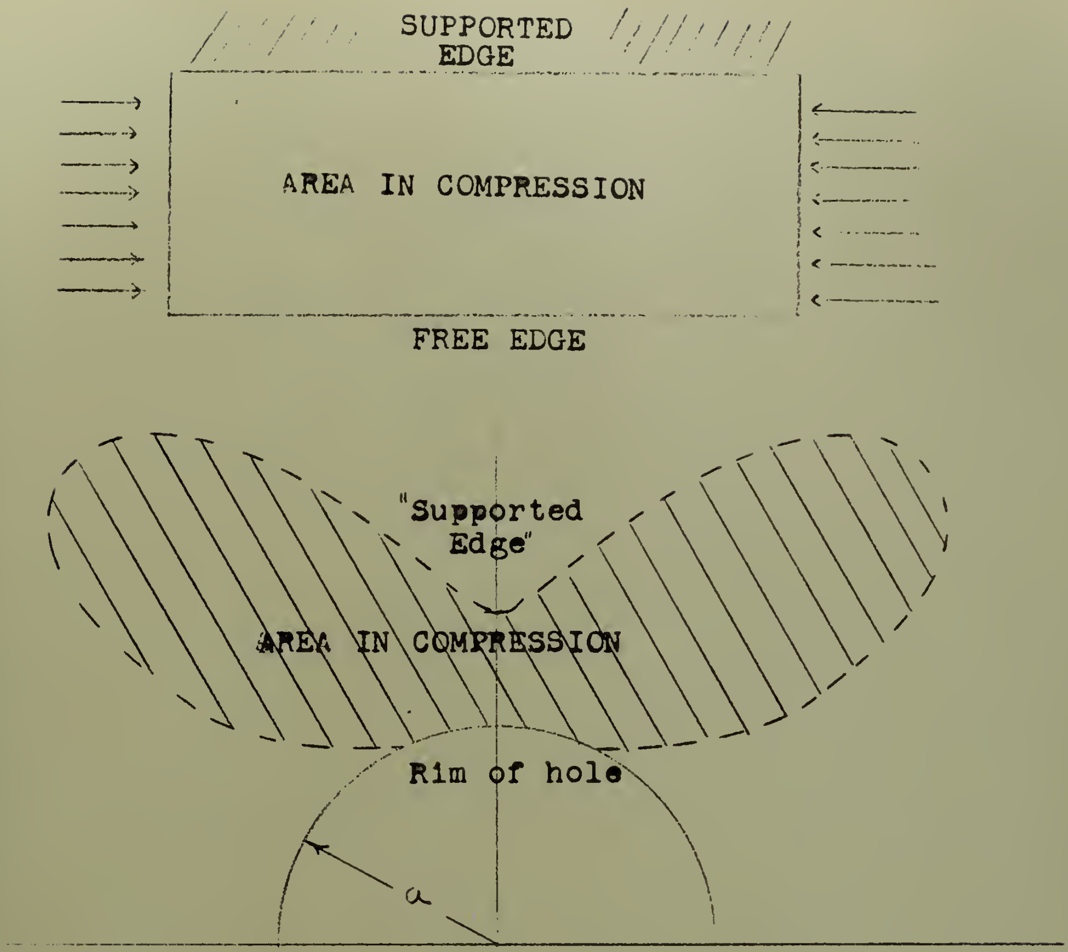


Figure 6

Thus, this analogy leads to a formula for the function K.
In this analogy, K is a function of the ratio of hole-diameter to plate-width, and, using t for plate thickness, we arrive at the relationship

$$K\left(\frac{d}{b}\right) = \frac{\sigma_{cr}}{E}\left(\frac{d}{t}\right)^2 \qquad \text{Equation 8}$$

where $\sigma_{cr} = \frac{P_{cr}}{bt}$

Pcr is the least value of P for which the flat form of equilibrium becomes unstable. (12)

b is the width of the sheet.

t is the thickness of the sheet.

The determination of Pcr then becomes the major problem.

If the initial deformation of the sheet is considered to be decomposed into a Fourier (type) series in the normal modes of buckling, we may write

$$W_n\ (x, y; 0) = \sum_{i=1}^{\infty} A_i \Psi_i\ (x, y).$$

where W_n (x, y; 0) is the initial deflection out of the plane of the sheet for all modes of buckling at no load. The Ψ (x, y) are the normal functions, and the Ai are coefficients which characterize the particular initial deflection. If a load P is applied, the deformation alters according to the formula

$$W_n\ (x, y; P) = \sum_{i=1}^{\infty} \frac{A_i \Psi_i (x, y)}{(1 - P/P_i)}.$$

(This type of equation is developed by Southwell for long struts in Reference 8, pp. 425-427.)

where P_i is the buckling load associated with the normal function Ψ_i.
Since the buckling load and normal functions are numbered so that $P_1 < P_2 < P_3 \ldots$, as P increases, the first term of the series is the first to become unbounded, and for values of P near P_1,

$$W\ (x, y; P) = \frac{A_1 \Psi_1 (x, y)}{1 - P/P_1}$$ is obtained.

By differentiating twice with respect to a given direction (along the y axis in this case), expressions for curvature are obtained.

$$ky\ (x,\ y;\ P) = \sum_{i=1}^{\infty} \frac{A_i \frac{\partial^2}{\partial y^2} \psi_i (x, y)}{(1 - P/P_i)}$$

At the point of maximum compressive stress, x = a, y = 0, this becomes

$$ky = \sum_{i=1}^{\infty} \frac{C_i}{1 - P/P_i}$$

If strain gages are installed to measure the change in curvature, the relationship is obtained,

$$B - b' = \sum_{i=1}^{\infty} \frac{D_i}{1 - P/P_i}$$

where b' and D_i are constants for a particular sheet with values unknown.

As P increases, the first term dominates, and

$$B - b' = \frac{D_1}{1 - P/P_1}$$

For P = 0 $\quad B_o - b' = D_1$

where B_o is the initial value of B. Thus

$$B - b' = \frac{B_o - b'}{1 - P/P_1}$$

By algebraic manipulation, this can be brought into the form,

$$\frac{\Delta B}{P} = \frac{\Delta B}{P_1} + \frac{B_o - b^1}{P_1}$$

Equation 9

and

$$\frac{1}{P} = \frac{1}{P_1} + \left(\frac{B_o - b^1}{P_1}\right) \frac{1}{\Delta B}$$

Equation 10

where $\Delta B = B - B_o$.

In Equation 9, it is seen that a plot of $\Delta B/P$ as ordinate versus ΔB as abscissa gives a straight line with intercept $(B_o - b')/P_1$ and slope $1/P_1$, and it is this slope that gives a value of P_1 which must be determined.

In Equation 10, it is seen that a plot of $1/P$ as ordinate versus $1/\Delta B$ as abscissa gives a straight line with intercept $1/P_1$ and slope $(B_o - b')/P_1$, and the point of intercept giving $1/P_1$ is what must be determined.

If all values of D_i were zero except only D_1, the results obtained from these plots would be exact, until they were rendered invalid either by large geometry effects as P approaches P_1, or by the effect of inelastic action at the point of the highest stress in altering the stress distribution, thus changing the value of D_1. In such a case, sufficiently long straight line segments -- so as to permit determining the value of P_1 by either the slope or the intercept method -- could be expected.

However, generally in practice no D_i vanishes, and Equations 9 and 10 are only approximations, the validity of which may be very poor for small values of P. For example, Figures 13 and 14 and Table 6 illustrate a test in which evidently D_2 was larger than D_1 and of opposite sign.

Thus, Equations 9 and 10 are likely to be invalid for small values of P and also invalid for large values of P (due either to inelastic action or large geometry). If the ranges of invalidity overlap, the test does not yield useful results. If not, we may be able to find an intermediate region where a straight line can be drawn through experimental points so as to give a value of P_1.

2. Experimental Procedure.

The initial attempts to detect and measure the deflection out of the plane of the sheet, caused by the compressive forces at the edge of the hole, were performed on very thin shim stock, from .001 to .005 inches thick. The hole was one-half inch in diameter. Any attempt to attach anything to this thin shim stock was found to reinforce it and thereby reduce or eliminate the buckling deflection which was being observed.

Thus, the optical lever principle single mirror system would not work properly, because a mirror glued directly to the area observed would reinforce this area, as would a lever to move a remote mirror. Strain gages attached to the shim stock also reinforced it to such an extent that no deflection out of the plane could be detected. Accordingly, a calibrated telescope system was employed to attempt to measure the magnitude of the deflection by observing its shadow created by a light through a slit at the edge of the shim stock sheet. The variation was so minute that measurement was not possible. Next, an electronic instrument was employed, a Q meter, to attempt to measure the change in capacitance caused by the deflection of the shim stock sheet and a small piece of metal used as the other plate of the capacitor. This too was unsatisfactory, again because the change was too minute to cause a measurable change in capacity.

Finally the decision was made that a heavier sheet would have to be used so that strain gages could be attached to it. A total of 15 sheets was tested. The sheets were of 24S-T3 aluminum, with a modulus of elasticity of 10×10^6 psi, and a tensile yield strength of 50,000 psi. Two mild steel sheets were also tested, and they had a modulus of

elasticity of 30 x 10^6 psi. The strength data were the manufacturer's specifications. No tests were made of the modulus or yield strength. It was thought that the manufacturer's specifications were as close to the true values as could be obtained by a routine test on this thin sheet material in our laboratory. Extremely careful tests are necessary for this type of determination.

All sheets were 16 x 36 inches. Holes were cut in the sheets by drilling a pilot hole to accommodate the pilot of the fly cutter. The fly cutter was attached to a special shaft in the drill press. The diameter of the hole to be cut was determined by the distance of the cutting blade from the shaft. The cutting tool was made of hardened tool steel ground to a fine edge.

In the aluminum sheets of .020" thick, diameters of 1, 1.5, 2, 2.5, and 3 inches were tested. In the .040" thick sheets, diameters of 3, 3.5, 4, 4.5, 5, 5.5, and 6 inches were tested. The mild steel sheets were .032" thick, and diameters of 3 and 4 inches were tested.

Some 3003-H aluminum sheets were also tested, but these data were completely unsatisfactory, and the reason is thought to be that this sheet had no specific yield point, but yielded gradually throughout the test.

After the holes were cut, the strain gages were attached. Because it was desired to measure the strain causing the change in the radius of curvature, the grid of the gage was oriented so that it wove back and forth across the extension of the diameter of the hole parallel to the direction of tension. This area was considered the one of maximum displacement.

The two gages were mounted back to back on either side of the sheet;

see Figure 7. This resulted in temperature compensation and doubled electrical output. (6)

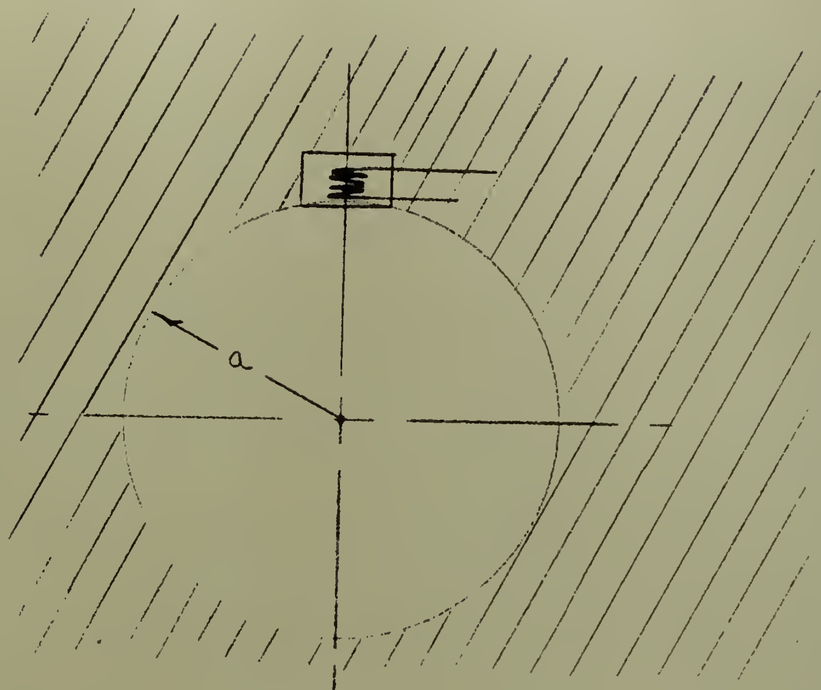


Figure 7

The grid was placed as close to the rim of the hole as possible. Thus, the edge of the paper encasing the grid lapped over the rim of the hole slightly. This paper was used to help align the second gage mounted on the back.

Great care had to be taken in mounting these gages in the same manner each time. Because the compressive stress attenuates so much with distance from the edge of the hole, it was considered essential that the grid be right at the edge of the hole. In order to accomplish this, Baldwin Model SR-4 type A-19 strain gages were used initially, because this type of gage has a grid width of only 1/16". Later, however, it was not possible to obtain any more of this type of gage from the manufacturer, and type A-8 gages were used. These gages have a gage width of 1/8 inches.

The gages gave almost identical results so that correlation of the data was possible.

The gages used to measure the strain caused at the maximum stress points were mounted singly, with a temperature compensating gage mounted on an unstressed piece of metal hung on the sheet being tested, so as not to interfere with the test. These gages were mounted at the edge of the hole on the diameter perpendicular to the direction of tension.

The surface of the metal was slightly buffed with emery cloth and cleaned with acetone before attaching the strain gages. Duco cement was used to attach the gages, and a Neg'ator constant-force spring was used to clamp the gages during the 50 hours' drying time. The drying process was aided by heating the gage with a lighted electric light bulb hung nearby.

When the gages were dry, the sheet was placed in the 120,000 pound Riehle Universal Hydraulic Testing Machine, shown in Figure 8. Two yokes were mounted in the clamp jaws of the machine, and to these yokes were attached the mounting bars for the sheet. These mounting bars measured the width of the sheet -- 16 inches. One side of this mounting bar arrangement was an integral part of the yoke, while the other side was a 1/4" metal bar. One-quarter inch holes were drilled in the mounting bars and in the sheet, in two rows, 3/4" apart, with holes spaced every one inch, so drilled that the holes in one row alternated with the holes in the other as shown in Figure 9. One-quarter inch bolts were used to clamp the sheet between the two mounting bars. These bolts were tightened hard and the arrangement gave uniform tension at both ends of the sheet along its width.

A. Buckling Curvature Strain Gages

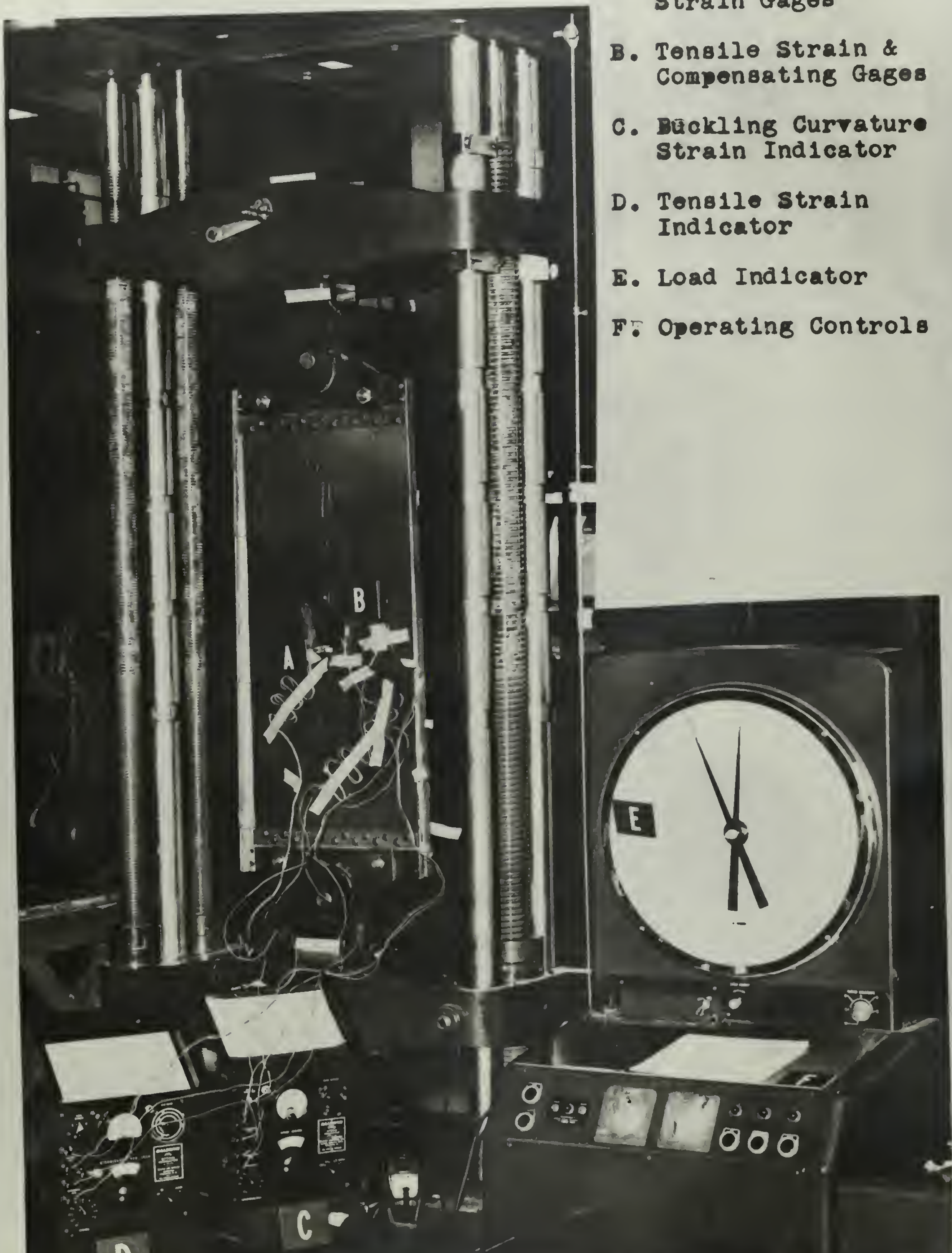
B. Tensile Strain & Compensating Gages

C. Buckling Curvature Strain Indicator

D. Tensile Strain Indicator

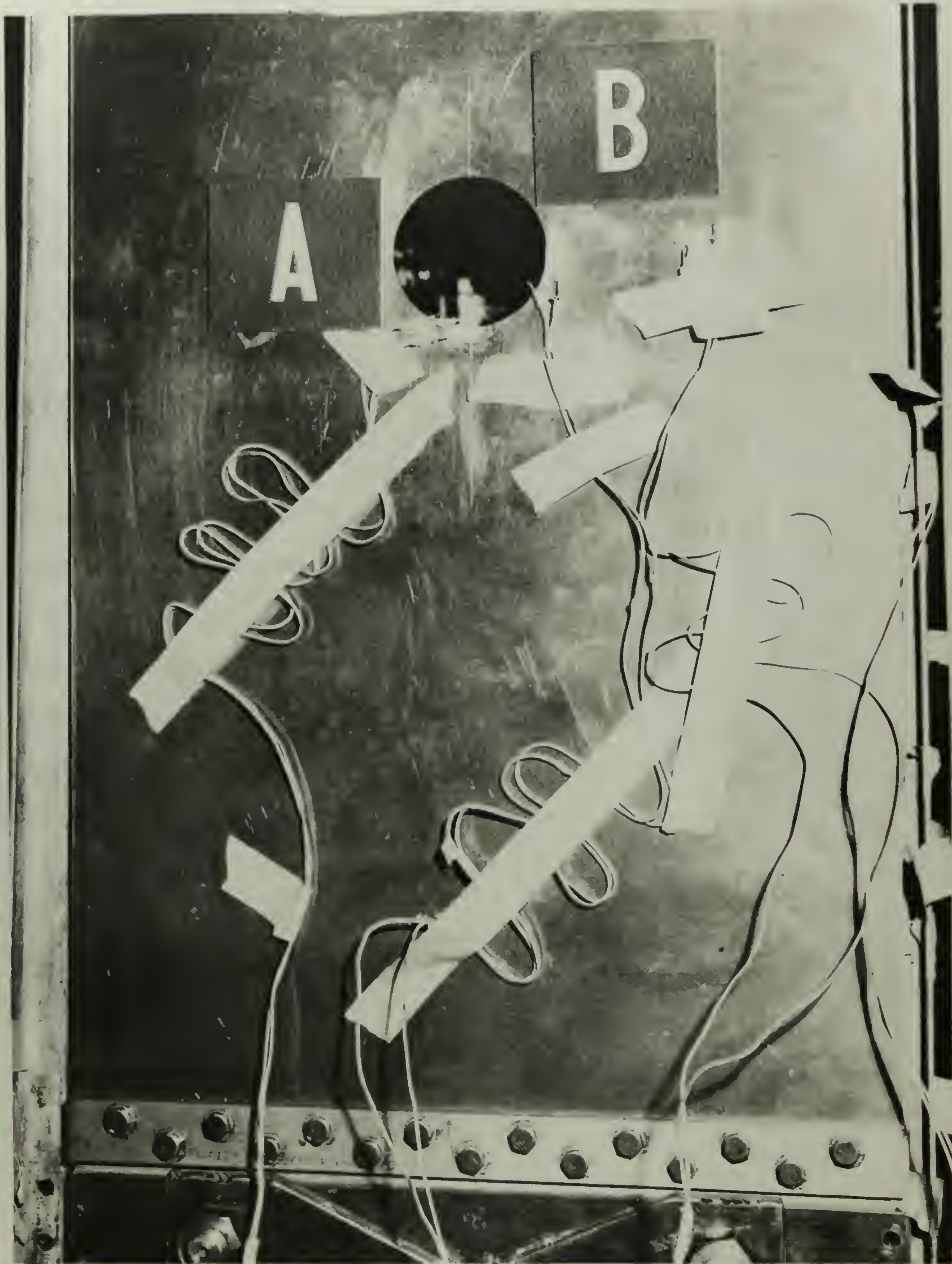
E. Load Indicator

F. Operating Controls



RIEHLE UNIVERSAL HYDRAULIC TESTING MACHINE

FIGURE 8



CLOSE - UP VIEW OF GAGES

AND MOUNTING BAR

FIGURE 9

After the sheet was mounted, wires were attached to the strain gages by twisting and soldering. These wires were then attached to Baldwin Static Strain Indicators. One indicator showed the strain in the bending-buckling gages, and the other the strain in the maximum stress gages.

The load gage on the testing machine was zeroed quite carefully before each run by disengaging the lower yoke so that there was no strain on the sheet, and placing 50 pounds of weight on the lower platform of the machine. The load indicating dial was then adjusted to 50 pounds, the weights removed, and the zero reading noted. Then the yoke was reclamped in the machine and the run started.

The .040" thick aluminum sheets were loaded to 4,000, 5,000, or 6,000 pounds initially, and then were unloaded in 100-pound increments to zero pounds. By loading to the maximum load initially, then unloading, the machine held the set loads accurately for a longer period. Readings were taken of the "B" gages, which actually measured the strain resulting from change in radius of curvature of the sheet at the point of attaching these "bending gages," and on the "T" gages, which measured the strain at the point of maximum stress.

The .020" thick aluminum sheets were loaded to 4,000 pounds initially, then unloaded in 50-pound increments to zero pounds. Readings were taken as above. The .032" steel sheets were the first tested. The procedure was not firmly established in these early runs, but, in general, readings were taken at 100-pound increments up to 5,000 pounds of load.

Three or more runs were made on each sheet to ensure that the data were reasonably consistent. These three runs purposely were not conducted consecutively, but were either performed one day after the other or at

widely different times in the same day. This was done to ensure that the gage readings, which are affected by temperature, would give results which could be evaluated in their true perspective and could be reproduced with the same accuracy at a later date.

It should be noted that when the sheet was mounted in the testing machine in the laboratory, one side of the sheet faced into a cold, relatively dark room, while the other side of the sheet faced the sky. Because of this unequal radiant heating, the gage readings were not truly temperature compensated and gave varying results.

Another phenomenon noted was that at certain times on some days there was considerable flicker of the needle in the strain indicators. This was an intermittent phenomenon, lasting from 15 minutes to an hour. With no changes in apparatus arrangement, it would stop and start for no apparent reason. Several attempts were made to analyze the cause, but to no avail. If the meter was jumping too much, the tests were stopped. However, if the oscillations were not too severe, the results were a slight scatter of points which would not have occurred otherwise.

For each run, K was calculated in the following manner: At each load increment, the B reading, T reading and P were recorded. Then ΔB was calculated for each load increment, and $\frac{\Delta B}{P}$ determined. Also, the reciprocals of P and ΔB were recorded.

$\frac{\Delta B}{P}$ versus ΔB and $\frac{1}{P}$ versus $\frac{1}{\Delta B}$ were plotted for each run.

P critical was determined by (1) the reciprocal of the slope and (2) the intercept method.

K was calculated for each run by $K_{d/b} = \frac{\sigma_{cr}}{E} \times (\frac{d}{t})^2$.

If there was too much scatter of points, the data were considered invalid; or, if one of the six values of K was in great difference, it

was discarded. The averaged values of K for each d/b ratio were then plotted versus d/b.

4. a. Results.

For thin metal sheets--loaded in tension at two opposite edges with two parallel free edges, and, having one hole in the center, whose diameter to width of sheet ratios varied from .125 to .378--a function of the ratio of the diameter of the hole to sheet width was determined. This function, called K, equal to $\frac{\sigma_{cr}}{E}\left(\frac{d}{t}\right)^2$, was determined for 24S-T3 aluminum sheets, having a tensile yield strength of 50,000 psi for sheet thicknesses of .020" and .040".

This function K is plotted versus the ratio of the diameter of the hole to sheet width in Figure 10.

Compiled data for the 15 sheets tested, showing sheet number, run number, diameter of hole, thickness of the sheet, material tested, critical loads, and K is shown in Table 4. It was not possible to detect buckling in .020" sheets with a hole diameter of 1.5" or less.

A typical plot of $\frac{\Delta B}{P}$ versus ΔB to determine Pcr by slope method is shown in Figure 11.

A typical plot of $\frac{1}{P}$ versus $\frac{1}{\Delta B}$ to determine Pcr by intercept method is shown in Figure 12.

A typical plot of load (P) versus change in maximum strain indicator (T) is shown in Figure 13.

All data and all plots for all runs and all sheets are filed in the library as a supplement to this thesis.

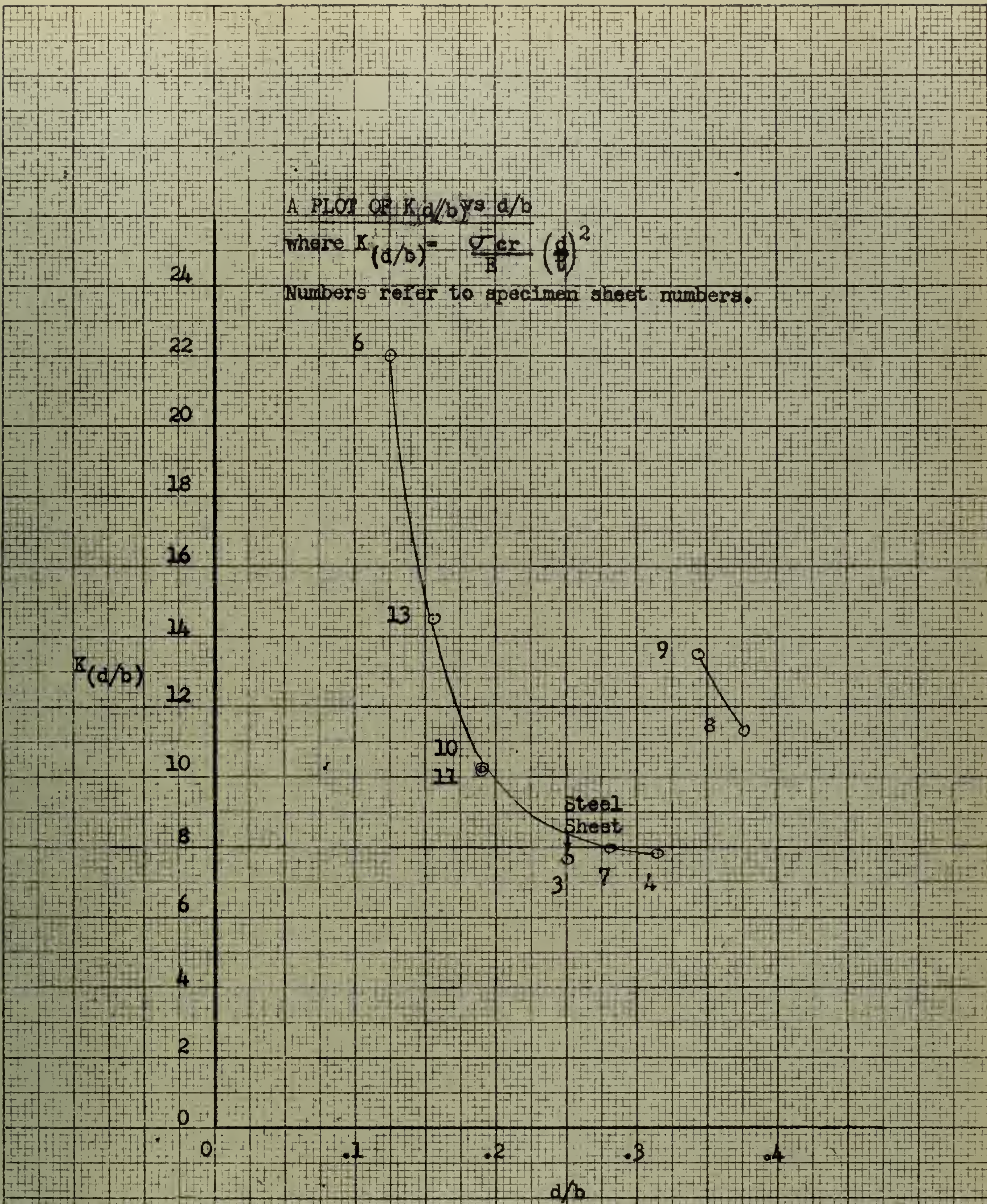

A PLOT OF $K_{(d/b)}$ vs d/b
where $K_{(d/b)} = \frac{\sigma_{cr}}{E}\left(\frac{d}{t}\right)^2$
Numbers refer to specimen sheet numbers.
$K_{(d/b)}$
24
22
20
18
16
14
12
10
8
6
4
2
0
0
.1
.2
.3
.4
d/b
6
13
9
8
10
11
Steel
Sheet
3
5
7
4

Figure 10

RESULTS

Sheet No.	Run No.	Desig.	Date of Test	Mat'l	E	b	t	d	$\frac{d}{b}$	Pcr	Pcr	σcr	σcr	K int	K slope	K avg
1	1	D	1/11	Mild Steel	30×10^6	16	.032	3	.188	TOO MUCH SCATTER OF POINTS						
1	2	E	1/16	Mild Steel	30×10^6	16	.032	3	.188	DATA UNSATISFACTORY						
1	3	A	1/17	Mild Steel	30×10^6	16	.032	3	.188	NEGATIVE INTERCEPT--DATA UNSATISFACTORY						
1	4	F	1/18	Mild Steel	30×10^6	16	.032	3	.188	INSIGNIFICANT CHANGE IN B READING						
2	1	-		(3004	10×10^6	16	.040	3	.188	THIS MATERIAL YIELDED SLIGHTLY THROUGHOUT						
2	2	G	1/24	(H14	10×10^6	16	.040	3	.188	THE RUN GIVING UNCERTAIN RESULTS						
2	3	H	1/24	(Alum	10×10^6	16	.040	3	.188							
2	4	-	1/28	(	10×10^6	16	.040	3	.188							
3	1	B	2/5	Mild Steel	30×10^6	16	.032	4	.250	5917	6660	11560	13000	6.02	6.77	
3	2	C	2/6	Mild Steel	30×10^6	16	.032	4	.250	8197	9313	15990	18190	8.32	9.47	7.65
4	1	I	2/14	(2024	10×10^6	16	.040	5	.313	3356	3060	5258	4781	8.22	7.47	
4	2	J	2/18	(T-3	10×10^6	16	.040	5	.313	2924	2970	4569	4640	7.13	7.25	
4	3	K	2/19	(Alum	10×10^6	16	.040	5	.313	3330	3570	5210	5580	8.14	8.72	7.82
5	1	EE	2/22	(2024	10×10^6	16	.040	4	.250	7745	8264	DATA UNSATISFACTORY--TOO MUCH SCATTER				
5	3	DD	2/26	(T-3 (Alum	10×10^6	16	.040	4	.250	-	-	DATA UNSATISFACTORY--TOO MUCH SCATTER				
6	1	L	3/8	(2024	10×10^6	16	.020	2	.125		8020		25100		25.1	
6	2	M	3/8	(T-3	10×10^6	16	.020	2	.125		6944		21700		21.7	
6	3	N	3/8	(Alum	10×10^6	16	.020	2	.125		6153		19290		19.3	22.0
7	1	O	3/11	(2024	10×10^6	16	.040	4.5	.281	5076	4444	7930	7000	7.45	8.18	
7	2	P	3/18	(T-3	10×10^6	16	.040	4.5	.281	4030	4202	6280	6565	7.96	8.46	
7	3	Q	3/25	(Alum	10×10^6	16	.040	4.5	.281	3205	4854	5020	7584	6.34	9.65	8.00

TABLE 4

Sheet No.	Run No.	Desig.	Date of Test	Mat'l	E	b	t	d	$\frac{d}{b}$	Pcr	Pcr	σ_{cr}	τ_{cr}	K_{int}	K slope	K avg
8	1	V	4/23	(2024	10×10^6	16	.040	6	.375	3048	4000	4760	6250	10.72	14.06	
8	2	RR	4/24	(T-3	10×10^6	16	.040	6	.375	2690	3020	4210	4720	9.46	10.62	
8	3	Y	4/25	(Alum	10×10^6	16	.040	6	.375	3106	3510	4860	5480	10.93	12.35	11.36
9	1	R	3/26	(2024	10×10^6	16	.040	5.5	.344	4367	4761	6820	7439	12.9	14.02	
9	2	S	3/26	(T-3	10×10^6	16	.040	5.5	.344	4484		7000		13.2		
9	3	T	3/26	(Alum	10×10^6	16	.040	5.5	.344	4484	4838	7000	7559	13.3	14.3	13.54
10	1	AA	4/29	(2024	10×10^6	16	.040	3	.188	11380		17800		9.95		
10	2	BB	5/6	(T-3	10×10^6	16	.040	3	.188	10870		17000		9.56		
10	3	CC	5/6	(Alum	10×10^6	16	.040	3	.188		12500		19550		11.0	10.17
11	1	FF	5/13	(2024	10×10^6	16	.020	3	.188	1087	1500	3390	4680	9.74	10.52	
11	2	GG	5/14	(T-3	10×10^6	16	.020	3	.188	1220	1495	3810	4660	11.32	10.46	
11	3	HH	5/15	(Alum	10×10^6	16	.020	3	.188	1330	1420	4150	4440	9.34	9.99	10.23
12	1	II	5/17	(2024	10×10^6	16	.020	1.1	.0688	CORRECTED FOR METER DRIFT,						
12	2	JJ	5/17	(T-3	10×10^6	16	.020	1.1	.0688	DATA IS INCONCLUSIVE. BUCKLING						
12	3	KK	5/17	(Alum	10×10^6	16	.020	1.1	.0688	NOT DETECTED						
13	1	Z	5/8	(2024	10×10^6	16	.020	2.5	.156	DATA UNSATISFACTORY						
13	2	W	5/9	(T-3	10×10^6	16	.020	2.5	.156	2666	3180	8333	9950	13.0	15.6	
13	3	X	5/9	(Alum	10×10^6	16	.020	2.5	.156	3030	2975	9470	9300	14.8	14.5	14.5
14	1	LL	5/20	(2024	10×10^6	16	.020	1.5	.094	DATA UNSATISFACTORY. BUCKLING NOT DETECTED						
14	2	MM	5/21	(T-3	10×10^6	16	.020	1.5	.094	DATA UNSATISFACTORY. BUCKLING NOT DETECTED						
14	3	NN	5/21	(Alum	10×10^6	16	.020	1.5	.094	DATA UNSATISFACTORY. BUCKLING NOT DETECTED						

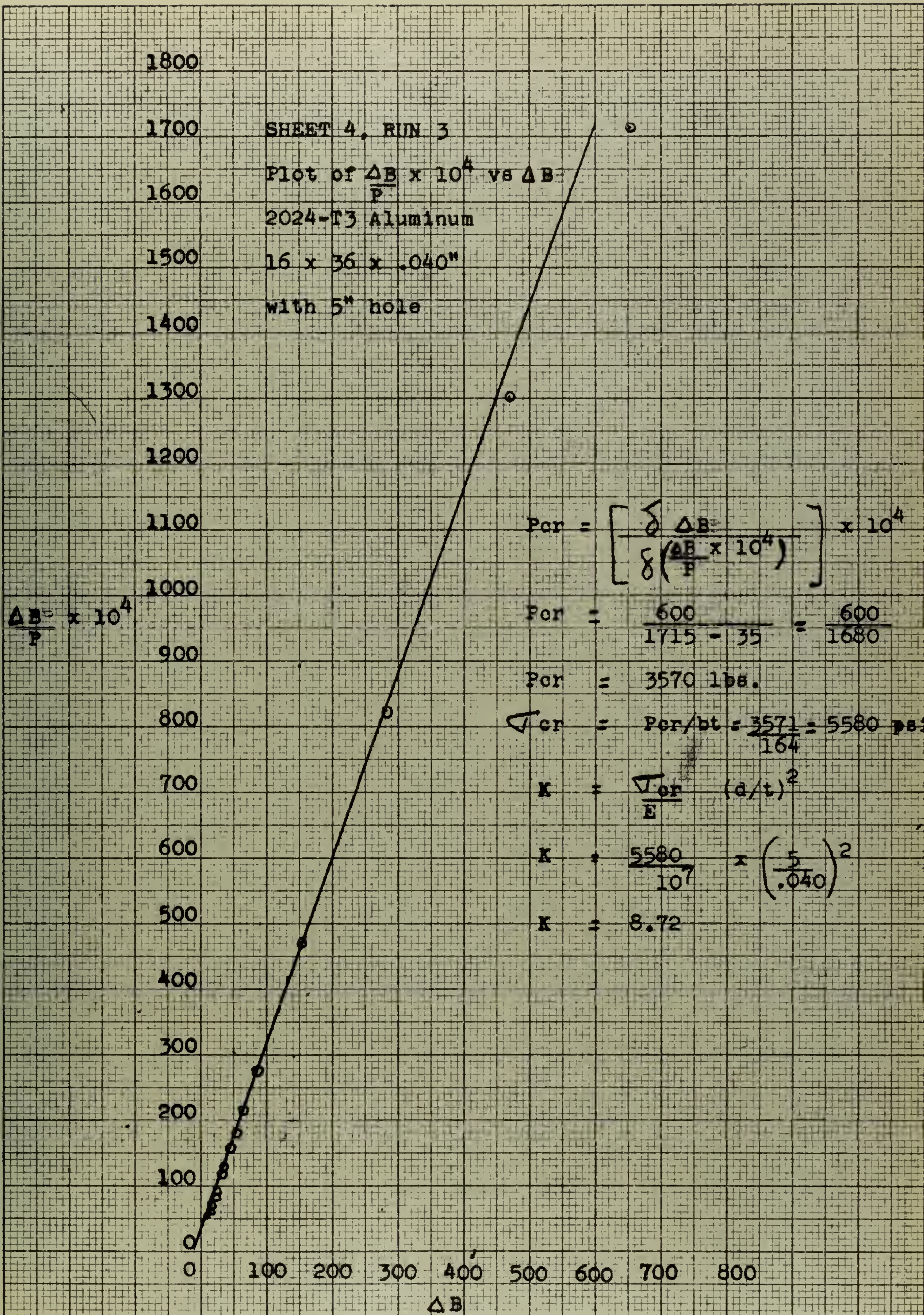

SHEET 4, RUN 3
Plot of ΔB/P x 10^4 vs ΔB
2024-T3 Aluminum
16 x 36 x .040"
with 5" hole
Pcr = [δ ΔB / δ(ΔB/P x 10^4)] x 10^4
Pcr = 600 / (1715 - 35) = 600/1680
Pcr = 3570 lbs.
σcr = Pcr/bt = 3571/.64 = 5580 psi
K = σcr/E (d/t)^2
K = 5580/10^7 x (5/.040)^2
K = 8.72
ΔB/P x 10^4
ΔB
1800
1700
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
0
100
200
300
400
500
600
700
800

Figure 11

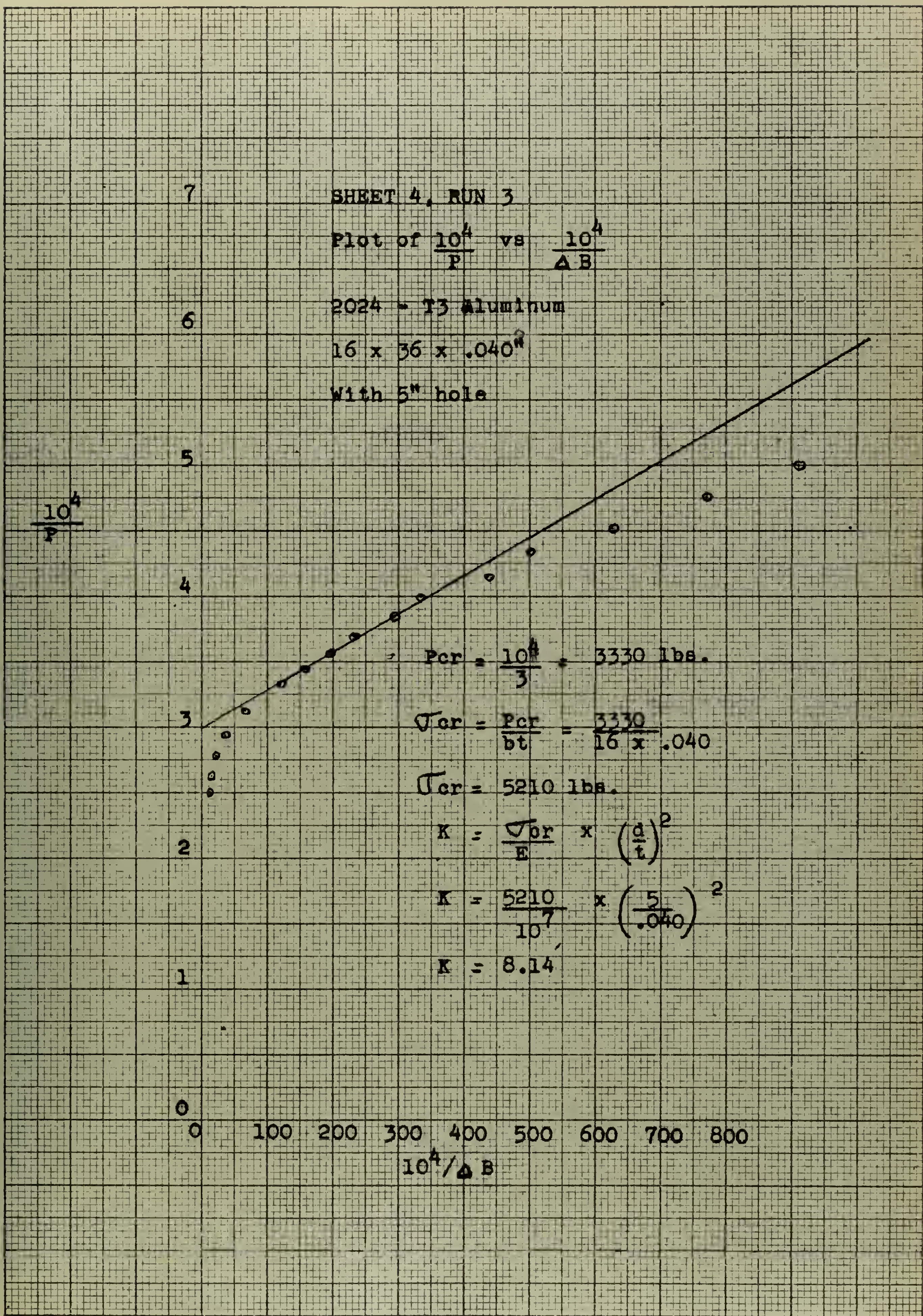

SHEET 4, RUN 3
Plot of $\frac{10^4}{P}$ vs $\frac{10^4}{\Delta B}$
2024 - T3 Aluminum
16 x 36 x .040"
With 5" hole
$\frac{10^4}{P}$
$10^4/\Delta B$
0
1
2
3
4
5
6
7
0
100
200
300
400
500
600
700
800
$P_{cr} = \frac{10^4}{3} = 3330$ lbs.
$\sigma_{cr} = \frac{P_{cr}}{bt} = \frac{3330}{16 \times .040}$
$\sigma_{cr} = 5210$ lbs.
$K = \frac{\sigma_{cr}}{E} \times \left(\frac{d}{t}\right)^2$
$K = \frac{5210}{10^7} \times \left(\frac{5}{.040}\right)^2$
$K = 8.14$

Figure 12

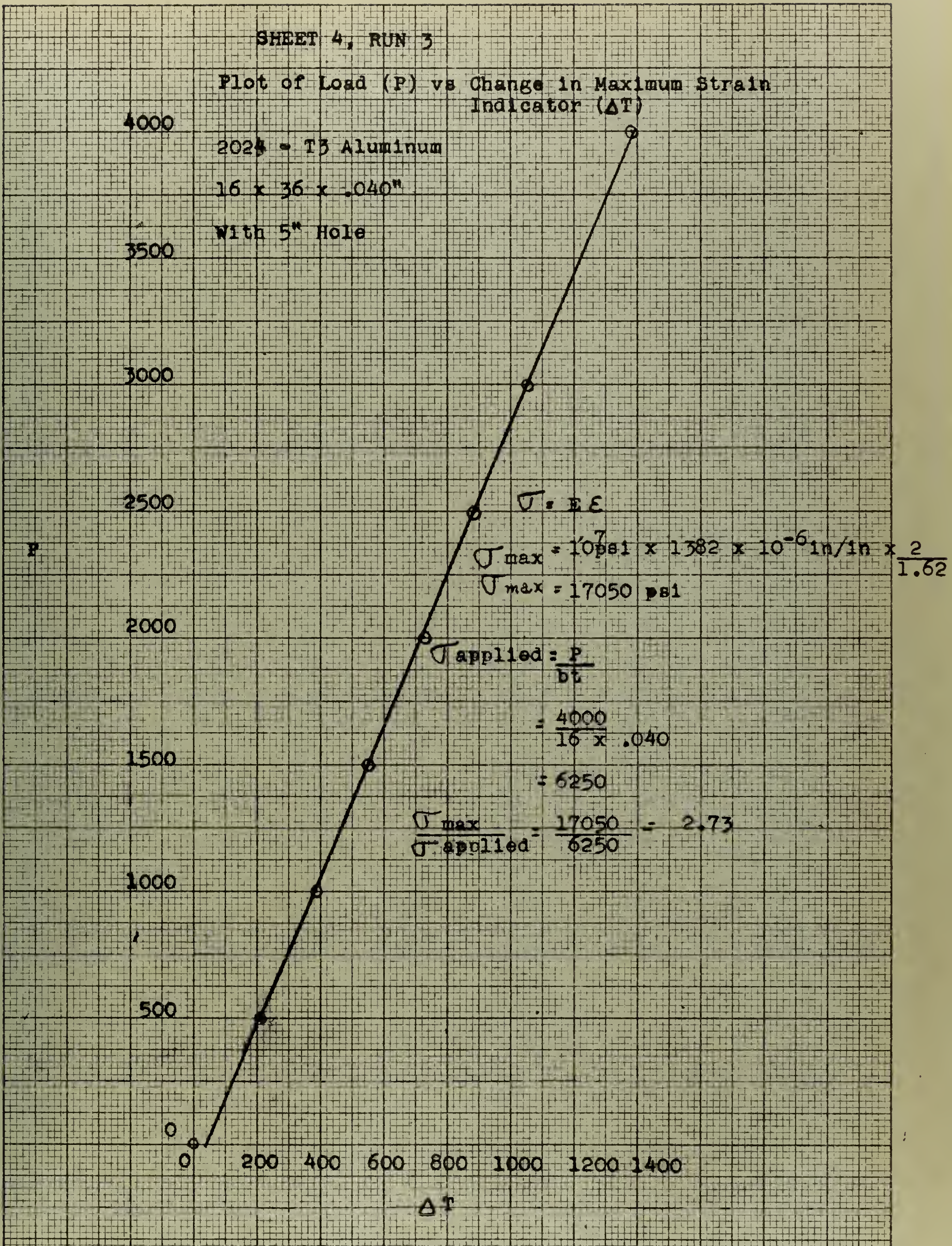

SHEET 4, RUN 3
Plot of Load (P) vs Change in Maximum Strain Indicator (ΔT)
2024 - T3 Aluminum
16 x 36 x .040"
With 5" Hole
4000
3500
3000
2500
2000
1500
1000
500
0
P
0
200
400
600
800
1000
1200
1400
ΔT
σ = E ε
σ max = 10^7 psi x 1382 x 10^-6 in/in x 2/1.62
σ max = 17050 psi
σ applied = P/bt
= 4000/16 x .040
= 6250
σ max/σ applied = 17050/6250 = 2.73

Figure 13

SHEET 4 - RUN 3 K

16 x 36 x .040" 2024 T3 Aluminum
With 5" Hole
A-8 Gage
Gage Factor 1.62
Gage Resistance 59.5 ohms

Load P	$\frac{1}{P} \times 10^4$	B	ΔB	$\frac{1}{\Delta B} \times 10^4$	$\frac{\Delta B}{P} \times 10^4$	T	ΔT
0		649				878	0
100	100	645	-4			925	
200	50	644	-5			965	
300	33.3	645	-4			1005	
400	25.0	642	-7			1054	
500	20.0	642	-7			1090	212
600	16.7	642	-7			1127	
800	12.5	643	-6			1198	
1000	10	644	-5			1265	387
1200	8.33	646	-3			1331	
1400	7.14	649	0			1398	
1500	6.67	650	+1	104	6.67	1430	552
1600	6.24	651	+2	5000	12.25	1463	
1700	5.88	652	+3	3333	17.65	1499	
1800	5.56	655	+6	1660	33.33	1532	
1900	5.26	656	+7	1428	36.84	1554	
2000	5.00	660	11	909	55.00	1599	721
2100	4.76	662	13	769	61.90	1631	
2200	4.54	665	16	625	72.73	1662	
2300	4.35	669	20	500	86.96	1699	
2400	4.16	672	23	435	95.83	1730	
2500	4.00	679	30	333	120.0	1761	883
2600	3.84	683	34	294	130.8	1793	
2700	3.70	692	43	233	159.3	1831	
2800	3.57	700	51	196	182.1	1862	
2900	3.45	712	63	159	217.2	1900	
3000	3.33	732	83	120	276.7	1929	1051
3200	3.13	800	151	66.2	471.9	1995	
3400	2.94	930	281	35.5	826.5	2054	
3600	2.78	1118	469	21.3	1303	2124	
3800	2.63	1300	651	15.4	1713	2195	
4000	2.50	1480	831	12.0	2077	2260	1382

TABLE 5

b. Discussion of Results.

The percentage difference of values of K, obtained on a single sheet from run to run, seemed quite high (up to 20%). Therefore, a review of the technique employed and its sources of error seemed necessary.

The sources of error were:

(1) Strain gages

(a) Not attached firmly.

(b) Leads not connected properly.

(c) Grids not oriented parallel to one another on opposite sides of the sheet.

(d) Uncompensated temperature error in gages.

(2) Deformations in rim of hole

(a) Causes

(b) Effects

(3) Mode of buckling if not primary

(4) A non-parallel tension across sheet

Upon investigation of these possible sources of error, it was found that some did not affect the results and others were minor, but that some were very real and major problems for which experimental technique must be improved.

In the strain gages, in those runs which gave uncertain results, visual inspection was made of the gages for possible loose glue and poor electrical connection. The readings were checked at the same loads to see that the gages read the same. The machine was set at an intermediate load, and the strain indicator observed for possible drift due to temperature variation. If this inspection indicated no errors, the results were considered valid.

In order to check the adequacy of the technique used in orienting the grids on all the sheets tested, two pairs of gages were glued on sheet 13, at opposite ends of the diameter. The results obtained, shown in Table 6, were plotted on the same graph and are shown in Figures 14 and 15. The coincidence of these points shows that, at least for this sheet, the gages were reading exactly the same strains; and therefore the orientation of grids was alike. If this investigation were to be continued, two pairs of buckling gages would be used on all sheets.

The possibility of different initial deformations in the area surrounding the hole is great. The sharpness of the cutting tool, the speed of cutting, and the roundness of the hole are all factors that contributed to this initial deformation. The effect of this was in the mode of buckling which occurred because of this deformation. Only in those cases in which the primary mode component was in the opposite direction to the secondary or higher mode components could this error be detected. Then only was it detected because eventually, as the sheet was loaded, the strain indicator would start to reverse its readings. If the secondary and tertiary modes of buckling were in the same direction as the primary, this would cause a large initial rate of change of buckling strain, then a tapering off as the primary mode exceeded the secondary. The curve for determination of Pcr might then have two or more approximately straight line portions which would have to be examined. Which portion was meaningful would be difficult to assess. Therefore, this presents itself as the greatest source of error.

The mounting of the sheet in the yoke so that tension was perpendicular to the edge of the sheet could be accomplished only if (1) the sheet was

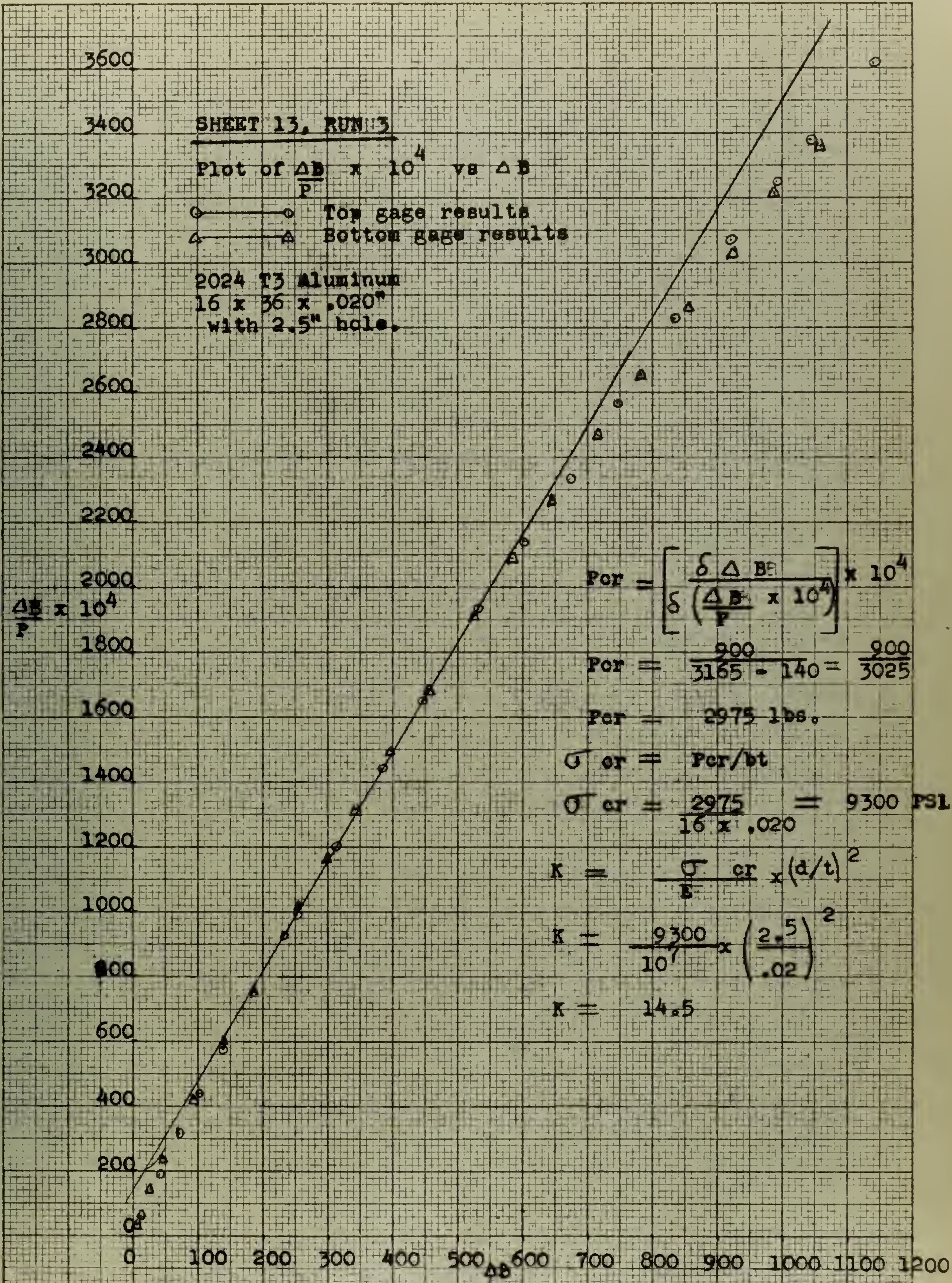
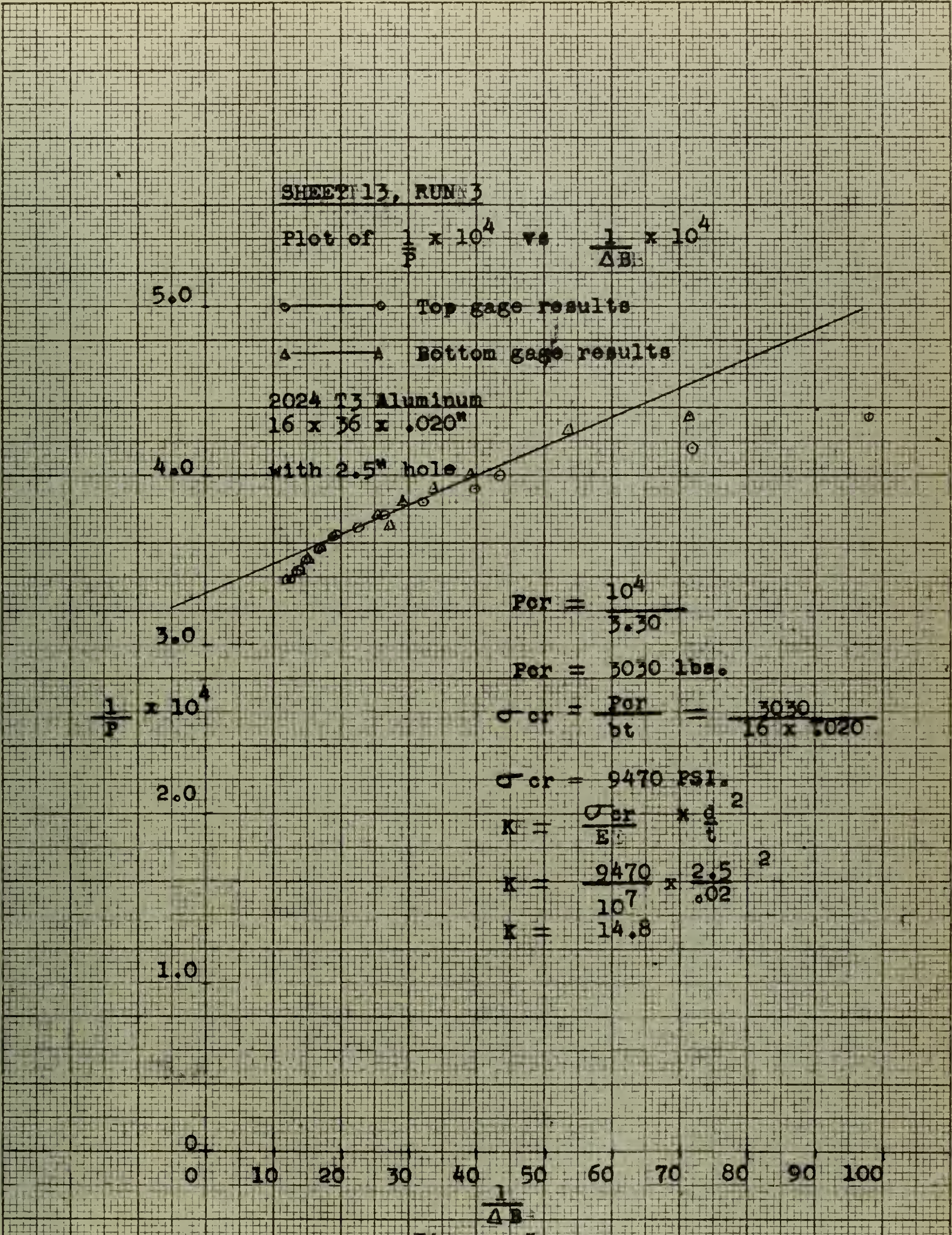

SHEET 13, RUN 3
Plot of $\frac{\Delta B}{P} \times 10^4$ vs ΔB
Top gage results
Bottom gage results
2024 T3 Aluminum
16 x 36 x .020"
with 2.5" hole.
$\frac{\Delta B}{P} \times 10^4$
ΔB
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
3000
3200
3400
3600
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
$P_{cr} = \left[\frac{\delta \Delta B}{\delta\left(\frac{\Delta B}{P} \times 10^4\right)}\right] \times 10^4$
$P_{cr} = \frac{900}{3165 - 140} = \frac{900}{3025}$
$P_{cr} =$ 2975 lbs.
$\sigma_{cr} = P_{cr}/bt$
$\sigma_{cr} = \frac{2975}{16 \times .020} = 9300$ PSI
$K = \frac{\sigma_{cr}}{E} \times (d/t)^2$
$K = \frac{9300}{10^7} \times \left(\frac{2.5}{.02}\right)^2$
$K = 14.5$

Figure 14


SHEET 13, RUN 3
Plot of $\frac{1}{P} \times 10^4$ vs $\frac{1}{\Delta B} \times 10^4$
Top gage results
Bottom gage results
2024 T3 Aluminum
16 x 36 x .020"
with 2.5" hole
$P_{cr} = \frac{10^4}{3.30}$
$P_{cr} = 3030$ lbs.
$\sigma_{cr} = \frac{P_{cr}}{bt} = \frac{3030}{16 \times .020}$
$\sigma_{cr} = 9470$ PSI.
$K = \frac{\sigma_{cr}}{E} \times \frac{d}{t}^2$
$K = \frac{9470}{10^7} \times \frac{2.5}{.02}^2$
$K = 14.8$
$\frac{1}{P} \times 10^4$
5.0
4.0
3.0
2.0
1.0
0
0
10
20
30
40
50
60
70
80
90
100
$\frac{1}{\Delta B}$
Figure 15

SHEET 13 - RUN 3 X

16 x 36 x .020" 2024 T3 Aluminum
2.5" Hole
A-8 Gage
Gage Factor 1.59
Gage Resistance 59.5 ohms

Load P	$\frac{1}{P} \times 10^4$	Top Gage B_1	B_1	$\frac{1}{P} \times B_1$	$\frac{1}{B_1} \times 10^4$	Botton Gage B_2	B_2	$\frac{1}{P} \times B_2$	$\frac{1}{B_2} \times 10^4$
0		630				1359			
100		621				1372			
200		621				1381			
300		609				1382			
400		607				1402			
500		608				1409			
600		600				1402			
700		592				1408			
800		583				1411			
900		572				1410			
1000		571				1409			
1100		572				1404			
1200		568				1401			
1300		562				1400			
1400		575				1396			
1500		578				1382			
1600		582				1375			
1700		593				1362			
1800		611				1352	7	38.9	1430
1900		622				1332	27	142.1	370
2000	5	642	12	60	833	1311	48	240.0	208
2100	4.76	670	40	190	250	1289	70	333.0	143
2200	4.55	700	70	318	143	1265	94	427.3	106
2300	4.35	732	102	440	98	1219	140	608.6	71.4
2400	4.17	769	139	579	71.9	1172	187	757.0	53.5
2500	4.00	852	232	929	43.1	1104	255	1020	39.2
2550	3.92	882	252	988	39.7	1062	297	1165	33.7
2600	3.85	942	312	1200	32.1	1016	343	1319	29.2
2650	3.77	1012	382	1441	26.2	962	397	1498	25.2
2700	3.70	1075	445	1648	22.5	904	455	1685	27.0
2750	3.64	1162	532	1934	18.8	833	526	1913	19.0
2800	3.57	1230	600	2143	16.7	774	585	2089	17.1
2850	3.51	1301	671	2354	14.9	712	647	2270	15.5
2900	3.45	1375	745	2569	13.4	643	716	2468	14.0
2950	3.39	1463	833	2824	12.0	576	783	2654	12.8
3000	3.33	1550	920	3067	10.9	500	859	2863	11.6
3050	3.28	1622	992	3252	10.1	432	927	3039	10.8
3100	3.23	1678	1048	3380	9.5	372	987	3113	10.1
3150	3.17	1770	1140	3619	8.78	300	1059	3361	9.4

TABLE 6

perfectly rectangular, (2) the bolt holes were parallel to the edge of the sheet, (3) the yoke was suspended from its top mounting clamp and the sheet lined up squarely with the bottom clamp. Items (1) and (3) were accomplished on each of the sheets tested. However, there was some slight misalignment of the bolt holes in some of the sheets. This was not considered a bad misalignment, but may have been a contributing factor to errors in the values of K obtained.

Sheets 8 and 9 with values of d/b of .375 and .344 give values of K of 11.4 and 13.5. Referring to Figure 12, it is seen that this is an increase of K with an increase of d/b. This result was not anticipated. The procedure on these sheets withstood all the inspections mentioned above and the results are considered valid. The behavior of this type of configuration may be similar to that for a thin sheet bent into an angle and placed in compression, in which there is a decrease in K with an increase in length to width ratio, then a sudden increase in K, resulting in a scalloped shaped curve of K vs a/b. (13)

All things considered, the results of the tests are considered valid, and the curve of values for K versus d/b is considered correct.

5. Conclusions.

In a thin elastic sheet, with a hole in the center, subject to uniform tension along two opposite edges, buckling may occur in the area along the diameter parallel to the direction of tension near the rim of the hole.

The determination of the critical load applied at the edges of the sheet which will cause buckling was possible using Southwell's method of determining buckling loads in thin rods.

A factor K which depends upon the ratio of the diameter of the hole to the width of the sheet, such that

$$K_{(d/b)} = \frac{\sigma_{cr}}{E} \times \left(\frac{d}{t}\right)^2$$

was found for two thicknesses of aluminum with d/b ratios of .125 to .375. This value of K was found to agree with that for a mild steel sheet with a d/b ratio of .25.

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14. Timoshenko, S. and Goodier, J. N., Theory of Elasticity, McGraw-Hill, 1951.

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SHEET NR	RUN NR	DESIG	DATE OF TEST	MATL	E	b	t	d	d/b	Pcr INT	Pcr SLOPE	σcr INT	σcr SLOPE	K INT	K SLOPE	K AVG
3	1	B	2/5/57	MILD STEEL	3x10^7	16	.032	4	.250	5917	6660	11560	13000	6.02	6.77	
3	2	C	2/6/57	"	"	"	"	"	"	8196	9313	15990	18190	8.32	9.47	7.65
4	1	I	2/14	24S-T3 ALUM	1x10^7	"	.040	5	.3125	3356	3060	5258	4781	8.22	7.47	
4	2	J	2/18	"	"	"	"	"	"	2924	2970	4569	4640	7.13	7.25	
4	3	K	2/19	"	"	"	"	"	"	2932	3120	4581	4875	7.16	7.62	7.48
~~5~~	~~3~~	~~DD~~	~~2/26~~	~~"~~	~~"~~	~~"~~	~~"~~	~~4~~	~~.250~~	~~7745~~	~~8264~~	12100 ~~10,750~~	12920 ~~11450~~	~~10.75~~	~~11.45~~	12.5
6	1	L	3/8	"	"	"	.020	2	.125	11800	8020	36,700	25,100	~~36.7~~	25.1	
6	2	M	3/8	"	"	"	"	"	"		6944		21,700		21.7	
6	3	N	3/8	"	"	"	"	"	"		6153		19,290		19.3	22.0
7	1	O	3/11	"	"	"	.040	4.5	.281	5076	4444	7930	7000	7.45	8.18	
7	2	P	3/18	"	"	"	"	"	"	4030	4202	6280	6565	7.96	8.46	
7	3	Q	3/25	"	"	"	"	"	"	3205	4854	5020	7584	6.34	9.65	8.00
8	1	V	4/23	"	"	"	.040	6	.375	3048	4000	4760	6250	10.72 ~~14.08~~	14.06	
8	2	RR	4/24	"	"	"	"	"	"	2690	3020	4210	4720	9.46	10.62	
8	3	Y	4/25	"	"	"	"	"	"	3106	3510	4860	5480	10.93	12.35	11.36
9	1	R	3/26	"	"	"	.040	5.5	.344	4367	4761	6820	7439	12.9	14.02	
9	2	S	3/26	"	"	"	"	"	"	4484	6000	7000	9375	13.2	17.72	
9	3	T	3/26	"	"	"	"	"	"	4484	4838	7000	7559	13.3	14.3	14.24
~~10~~	~~1~~	~~AA~~	~~4/29~~	~~"~~	~~"~~	~~"~~	~~.040~~	~~3~~	~~.188~~	~~3623~~	~~1350~~	~~5670~~	~~2170~~	~~12.15~~	~~11.9~~	
10	2	BB	5/6	"	"	"	.040	3	.188	~~2150~~	12500	3360	13550	12.2	11.0	
10	3	CC	5/6	"	"	"	"	"	"	10810	18500	17000	18900	9.56	16.25	
10	1	AA	4/29	"	"	"	.040	3	.188	11380	–	17800	–	9.95		10.69
11	1	FF	5/13	"	"	"	.020	3	.188	1087	1500	3390	4680	9.74	10.52	
11	2	GG	5/14	"	"	"	"	"	.188	1220	1495	3810	4660	11.32	10.46	
11	3	HH	5/15	"	"	"	"	"	.188	1330	1420	4150	4440	9.34	9.99	10.23

6

7

$10^4/P$

5

5

4

3

0 1 2 $10^2/B$ 3 4 5

SHEET 1 RUN 1

SHEET NR	RUN NR	DESIG	DATE OF TEST	MATL	E	b	t	d	d/b	Pcr INT	Pcr SLOPE	σcr INT	σcr SLOPE	K INT	K SLOPE	K AVG.
12	1	II	5/17	24S-T3	10^7	16	.020	1.1"	.0688	2283	2650	7130	8280	2.16	2.51	
12	2	JJ	5/17	"	"	"	"	"	"	2500	2540	7820	7940	2.36	2.40	
12	3	KK	5/17	"	"	"	"	"	"	2475	2740	7740	8560	2.34	2.59	2.39
13	1	Z	5/8	"	"	"	"	2.5"	~~.375~~ .156	DATA	UNSAT			—	—	
13	2	W	5/9	"	"	"	"	"	"	2666	3180	8333	9950	13.0	15.6	
13	3	X	5/9	"	"	"	"	"	"	2967	3262	9270	10,200	14.6	15.9	14.8
~~14~~		~~LL~~														
14		MM	CORRECTED DATA SHOWS DATA UNSAT & INCONCLUSIVE.													
~~14~~		~~NN~~	~~5/20~~	~~"~~	~~"~~	~~"~~	~~"~~	~~1.5"~~	~~.0937~~		~~3430~~		~~10710~~		~~6.6~~	
15		OO														
15		PP														
15		QQ														

6
$10^4/P$
5
4
3

0 1 2 $10^2/B$ 3 4 5

SHEET 1 RUN 1

LOAD	$\frac{10^4}{P}$	B	B-B₀	$\frac{10^2}{\Delta B}$	$\frac{\Delta B \times 10^4}{P}$	T	ΔT	STRESS
P			ΔB					ΔT x 38.67
0	—	765				831	0	
100	100	828	-63			923	92	
200	50	834	-69			951	120	
300	33.3	834	-69			970	139	
400	25.0	829	-64			982	151	
500	20.0	820	-55			998	167	
600	16.7	811	-46	DISREGARD		1012	181	
700	14.3	801	-36			1029	198	
800	12.5	789	-24			1045	214	
900	11.1	781	-16			1056	225	
1000	10	771	-6			1072	241	
1100	9.09	764	+1	100	9.09	1087	256	
1200	8.33	757	+8	12.5	66.7	1099	268	
1300	7.69	752	13	7.69	100.0	1110	279	
1400	7.14	744	21	4.76	150.0	1128	297	
1500	6.67	740	25	4.00	167	1139	308	
1600	6.25	732	33	3.03	206	1151	320	
1700	5.88	729	36	2.78	212	1167	336	
1800	5.56	727	38	2.63	211	1181	350	
1900	5.26	710	55	1.82	289	1192	361	
2000	5	720	45	2.22	225	1206	375	
2100	4.76	715	50	2.0	238	1222	391	
2200	4.55	710	55	1.82	2.50	1238	407	
2300	4.35	708	57	1.75	248	1256	421	
2400	4.17	706	59	1.69	246	1271	440	

LOAD	$\frac{10^4}{P}$	B	B-B₀	$\frac{10^2}{\Delta B}$	$\frac{\Delta B}{P} \times 10^4$	T	ΔT	STRESS
P			ΔB					ΔT x 38.67
2500	4	704	61	1.64	244	1290	459	
2600	3.85	700	65	1.54	250	1301	470	
2700	3.70	692	73	1.37	270	1311	480	
2800	3.57	694	75	1.33	267	1326	495	
2900	3.45	691	78	1.28	269	1338	507	
3000	3.33	690	79	1.26	263	1354	523	
3100	3.23	688	81	1.23	261	1368	537	
3200	3.13	686	83	1.20	259	1380	549	
3300	3.03	683	86	1.16	261	1400	569	
3400	2.94	681	88	1.14	259	1410	579	
3500	2.86	680	89	1.12	254	1425	594	
3600	2.78	676	93	1.08	258	1440	609	
3700	2.70	674	95	1.05	257	1455	624	
3800	2.63	672	97	1.03	255	1470	639	
3900	2.56	670	99	1.01	254	1486	655	
4000	2.50	669	101	.990	253	1500	669	

SHEET 1 RUN 1

D

0 1 2 $10^2/B$ 3 4 5

$10^4/P$: 6 5 4 3

SHEET #1 36 x 6" WITH 3" HOLE IN CENTER 1/11/57
RUN 1 .032" THICK. MILD STEEL P1
MODULUS OF ELASTISICITY 3×10^7
YIELD STRENGTH 30000 PSI

FORCE	DIAL READING B-1 LOAD	UNLOAD		DIAL READING T-1 LOAD	UNLOAD
0	765	760		831	850
100	828	801		923	952
200	834	810		951	989
300	834	805		970	1017
400	829	794		982	1039
500	820	781		998	1053
600	811	766		1012	1068
700	801	753		1029	1082
800	789	742		1045	1098
900	781	735		1056	1108
1000	771	729		1072	1126
1100	764	722		1087	1136
1200	757	719		1099	1151
1300	752	713		1110	1162
1400	744	710		1128	1173
1500	740	708		1139	1187
1600	732	703		1151	1200
1700	729	700		1167	1213
1800	727	700		1181	1225
1900	710	696		1192	1237
2000	720	692		1206	1250
2100	715	690		1222	1260
2200	710	689		1238	1278
2300	708	687		1256	1285
2400	706	685		1271	1297
2500	704	683		1290	1311
2600	700	681		1301	1325
2700	692	680		1311	1336
2800	694	678		1326	1348
2900	691	677		1338	1361
3000	690	676		1354	1374
3100	688	674		1368	1387
3200	686	673		1380	1396
3300	683	672		1400	1410
3400	681	671		1410	1420
3500	680	671		1425	1434

SHEET 1 RUN 1

RP-216

ORIGINAL DATA SHEET 1 RUN 1 D

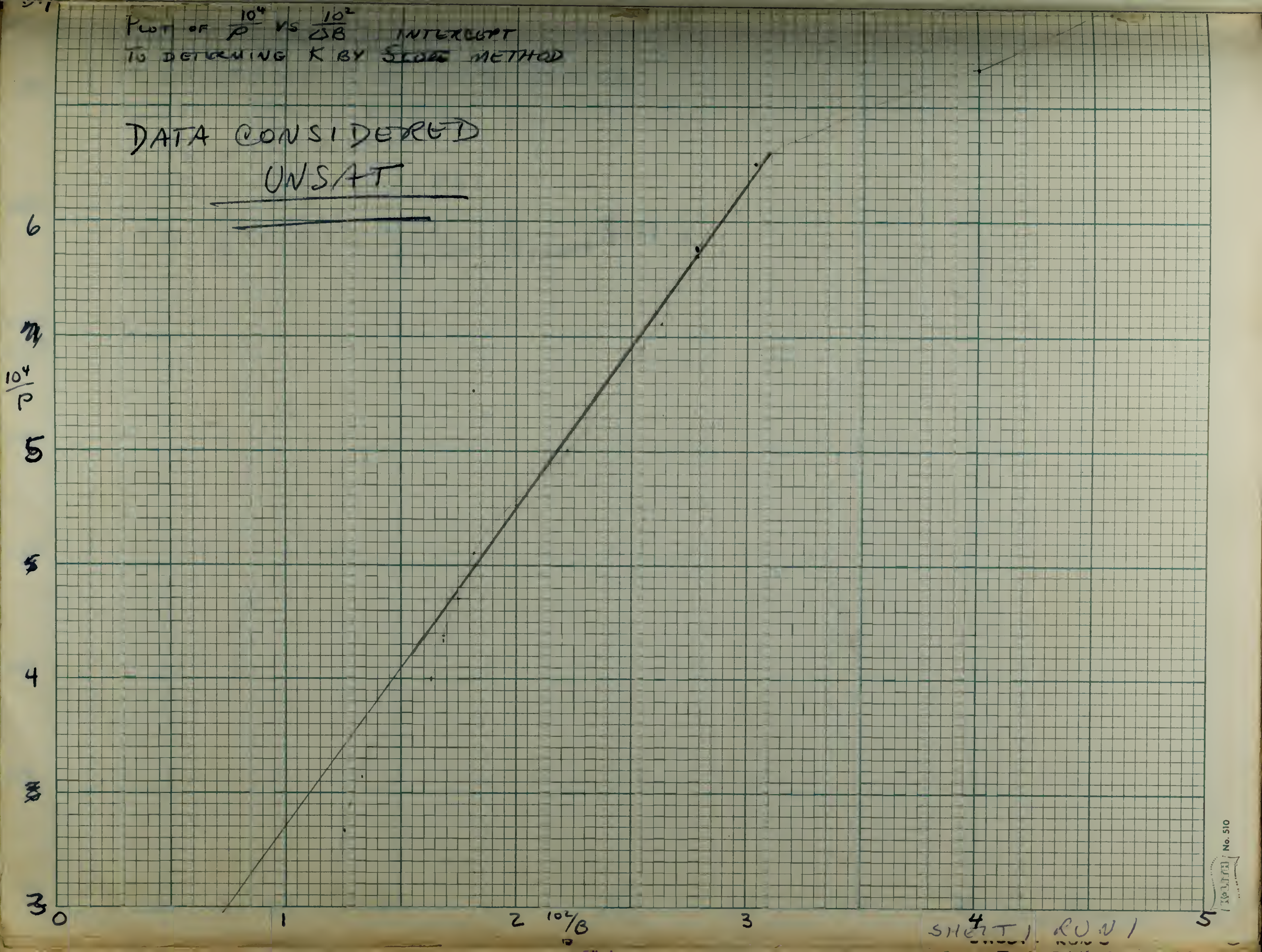
SHEET #1 RUN 1 P2 1/11/57

FORCE	B-1			T-1	
3600	676	670		1440	1448
3700	674	669		1455	1460
3800	672	669		1470	1476
3900	670	668		1486	1488
4000	669			1500	

RP-218

ORIGINAL DATA. SHEET 1 RUN 1 D

SHEET 1 RUN 1


PLOT OF $\frac{10^4}{P}$ VS $\frac{10^2}{\Delta B}$ INTERCEPT
TO DETERMINE K BY SLOPE METHOD
DATA CONSIDERED
UNSAT
6
5
4
3
$\frac{10^4}{P}$
0
1
2
3
4
5
$10^2/B$
SHEET 1 RUN 1
No. 510

PLOT OF $\frac{\Delta B \times 10^4}{P}$ VS ΔB

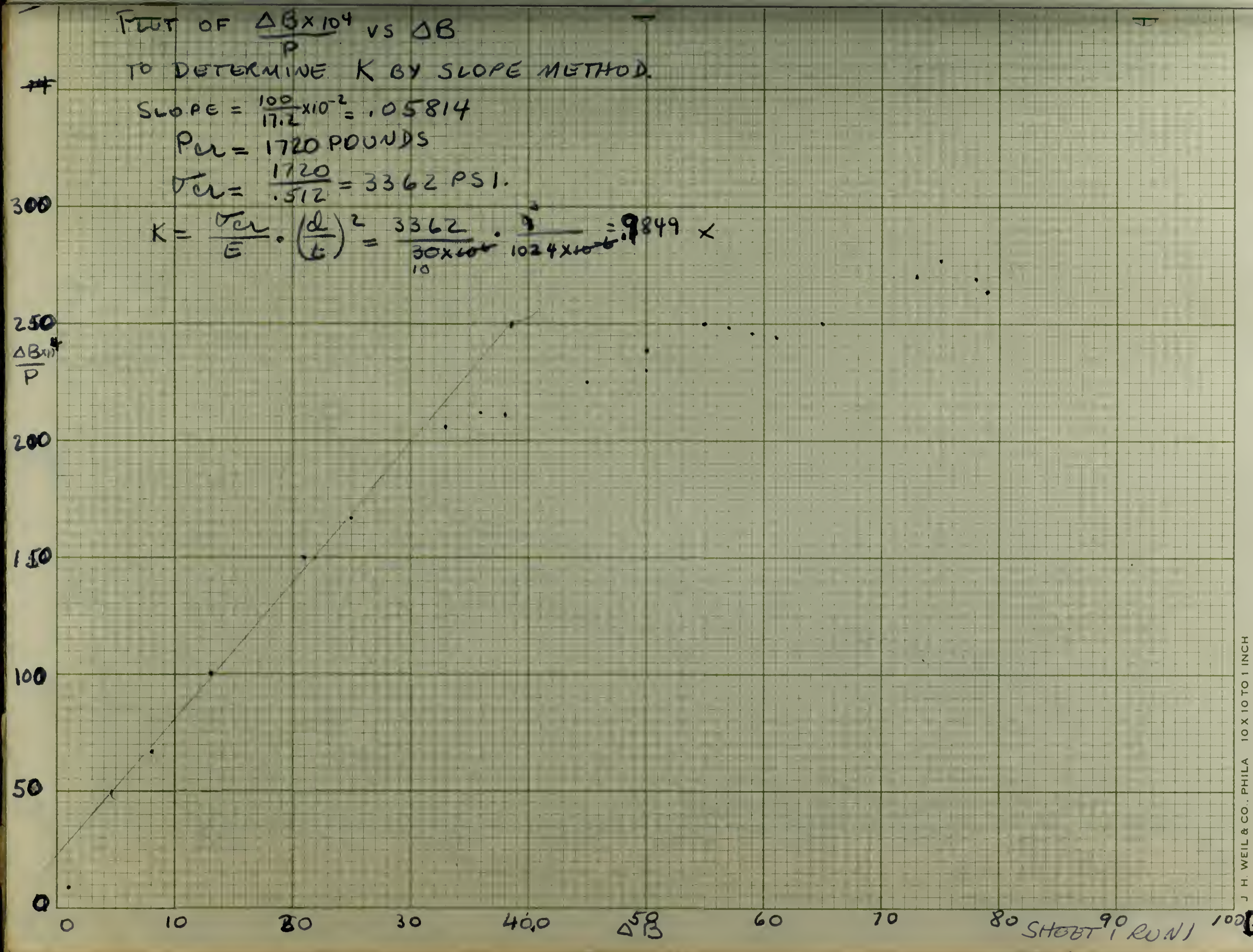
TO DETERMINE K BY SLOPE METHOD.

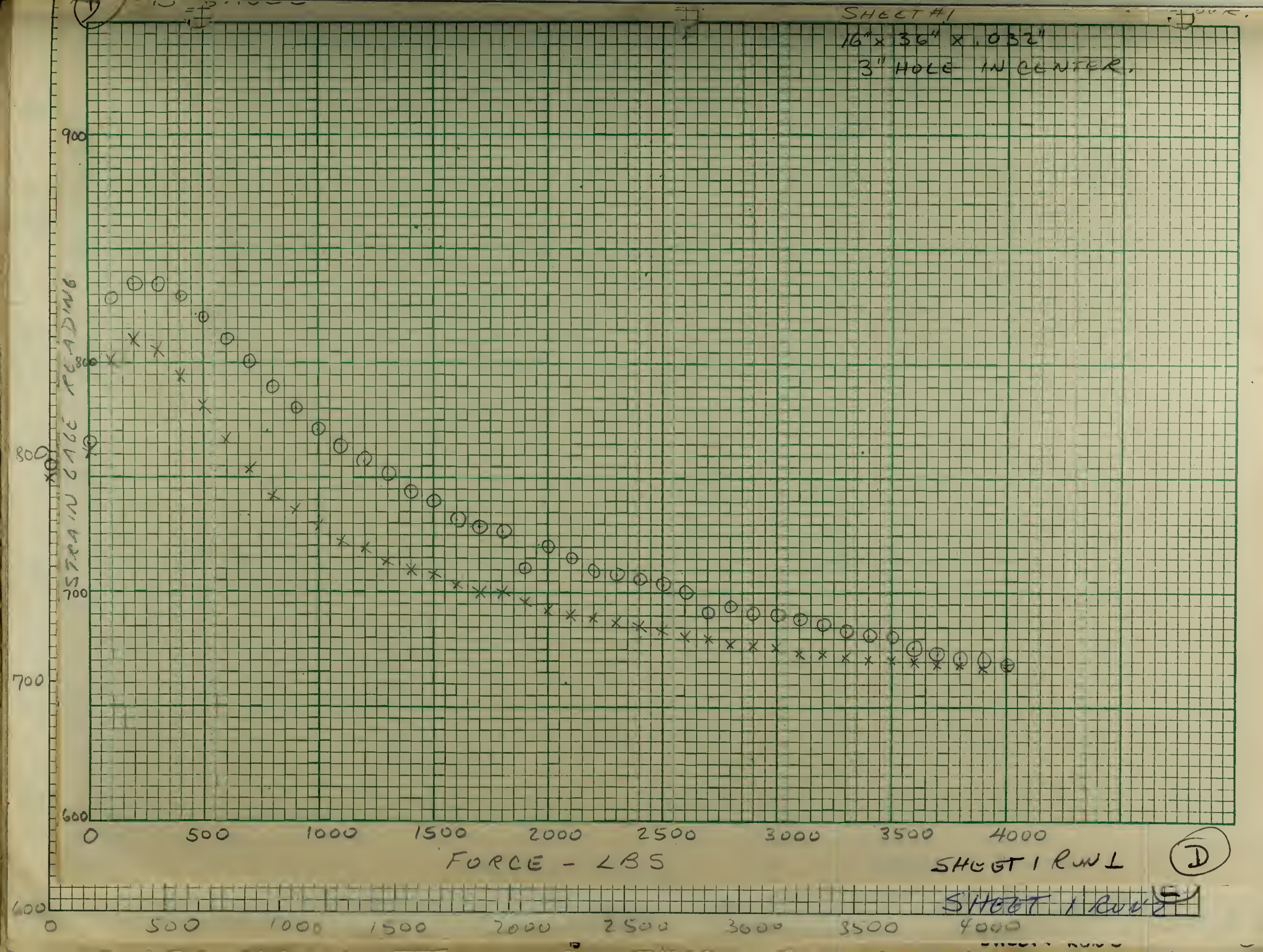
$SLOPE = \frac{100}{17.2} \times 10^{-2} = .05814$

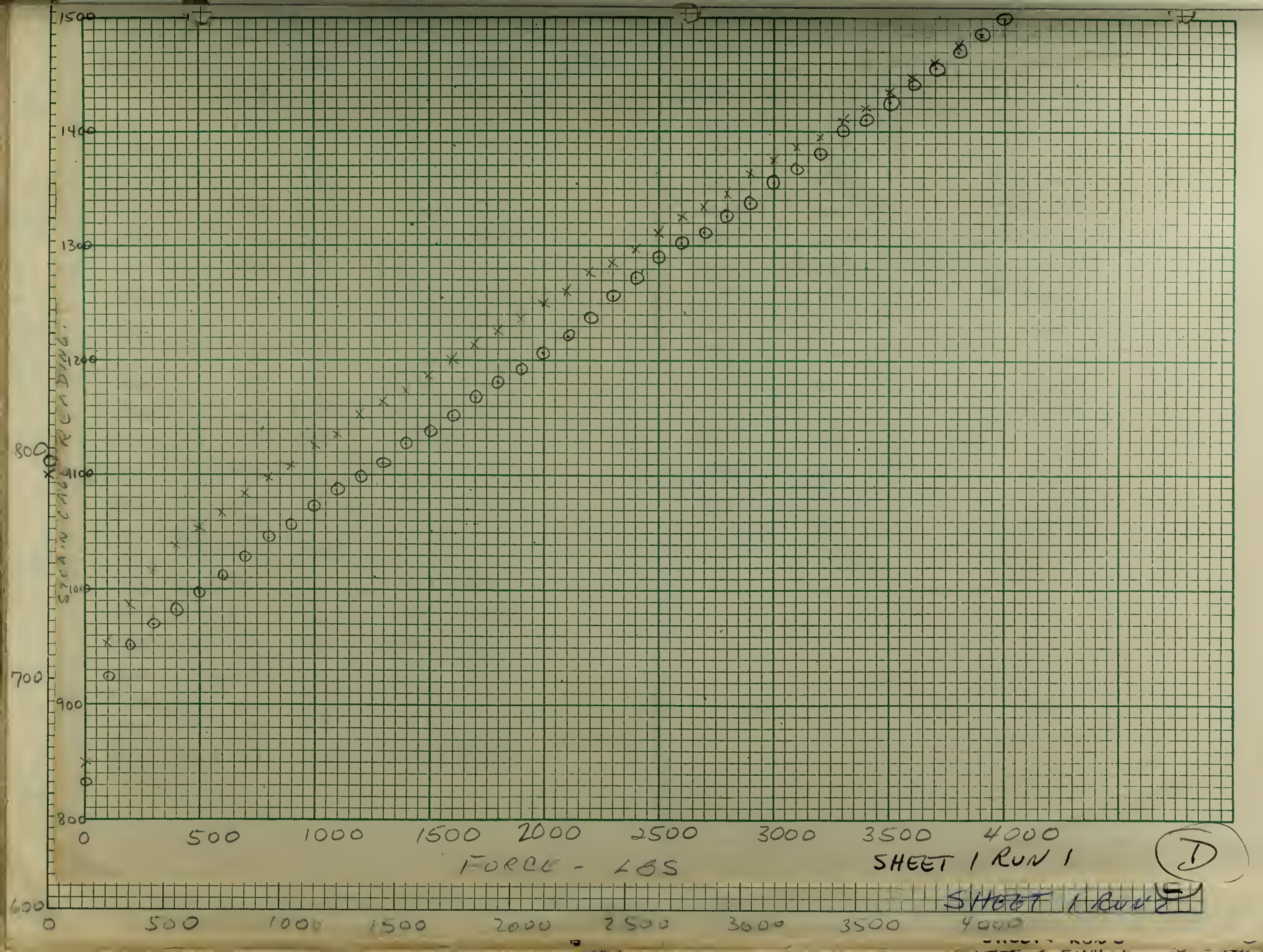
$P_{cr} = 1720$ POUNDS

$\sigma_{cr} = \frac{1720}{.512} = 3362$ PSI.

$K = \frac{\sigma_{cr}}{E} \cdot \left(\frac{d}{t}\right)^2 = \frac{3362}{30 \times 10^6} \cdot \frac{9}{1024 \times 10^{-6}} = .9849 \times$




SHEET #1
16" x 36" x .032"
3" HOLE IN CENTER.
STRAIN GAGE READING
900
800
700
600
0
500
1000
1500
2000
2500
3000
3500
4000
FORCE - LBS
SHEET 1 RUN 1
D
SHEET 1 RUN 2



STRAIN GAGE READING.
FORCE - LBS
SHEET 1 RUN 1
D
SHEET 1 RUN 2

LOAD	$10^4/P$ ⊥	B	$B-B_0$	$\frac{1}{\Delta B}$	$\frac{\Delta B}{P}$	T	ΔT	STRESS
P			ΔB			~~1169~~		$\Delta T \times 38.67$
0		794	0			1169	0	
100	1	786	8	125	8	1188		
200	5	772	18	833	6	1201		
300	333	760	34	294	113	1222		
400	250	744	50	2	125	1240		
500	2	735	59	169	118	1255		
600	166	728	66	152	110	1272		
700	143	720	74	135	106	1288		
800	125	711	83	120	104	1302		
900	111	702	92	109	102	1324		
1000	1	700	94	106	94	1335		
1200	833	689	105	952	875	1358		
1300	769	685	109	917	838	1370		
1400	714	682	112	893	800	1388		
1500	667	680	114	877	760	1402		
1600	625	678	116	862	725	1412		
1700	588	678	116	862	682	1429		
1800	556	672	122	820	678	1448		
1900	526	671	123	813	647	1460		
2000	500	672	122	820	610	1475		
2100	476	672	122	820	581	1488		
2200	455	672	122	820	555	1500		
2300	435	672	122	820	530	1512		
2400	417	672	122	820	508	1540		

⊥ LOAD	$10^4/P$	B	$B-B_0$	$\frac{1}{\Delta B}$	$\frac{\Delta B}{P}$	T	ΔT	ST ⊥ RESS
P								$\Delta T \times 38.67$
2500	400 ~~665~~	665	129	775	516	1550		
2600	385	668	126 ~~132~~	793	485	1570		
2700	370	668	126 ~~132~~	793	467	1582		
2800	354	665	129	775	461	1600		
2900	345	665	129	775	445	1615		
3000	333	662	132	758	440	1622		
3100	323	662	132	758	426	1640		
3200	313	661	133	752	416	1652		
3300	303	661	133	752		1665		
3400	294	661	133	752		1678		
3500	286	661	133	752		1690		
3600	278	661	133	752	369	1705		
3700	270	661	133	752		1720		
3800	263	661	133	752		1730		
3900	256	660	134	746		1749		
4000	250	660	134	746	335	1758		

SHEET 1 RUN 2

E.

~~SHEET 1 RUN 2~~

800

700

600

0 500 1000 1500 2000 2500 3000 3500 4000

RUN 2 SHEET 1 P1

1/16/57

LOAD	B READING LOADING	B READING UNLOADING		T READING LOADING	T READING UNLOADING
0	794	788		1169	1245
100	786	772		1188	1260
200	772	755		1201	1245
300	760	730		1222	1255
400	744	718		1240	1300
500	735	702		1255	1315
600	728	695		1272	1320
700	720	688		1288	1348
800	711	682		1302	1360
900	702	680		1324	1368
1000	700	688		1335	1380
~~1100~~	~~694~~	~~682~~		1345	1392
1200	689	678		1358	1402
1300	685	675		1370	1418
1400	682	670		1388	1422
1500	680	670		1402	1441
1600	678	670		1412	1452
1700	678	669		1429	1465
1800	672	668		1448	1480
1900	671			1460	1488
2000	672	665		1475	1500
2100	672	662		1488	1510
2200	672	660	SUMMIT	1500	1522
2300	672		SHEET	1512	1538
2400	672		LOADING	1540	1550
2500	665			1550	1565
2600	668			1570	1580
2700	668			1582	1595
2800	665			1600	1608
2900	665	660		1615	1620
3000	662	660		1622	1632
3100	662	661		1640	1642
3200	661	662		1652	1658
3300	661	662		1665	1670
3400	661	661		1678	1680

SHEET 1 RUN 2

RP-216

ORIGINAL DATA.

E

(E) RUN 2 SHEET 1 P2 1/16/57 JF

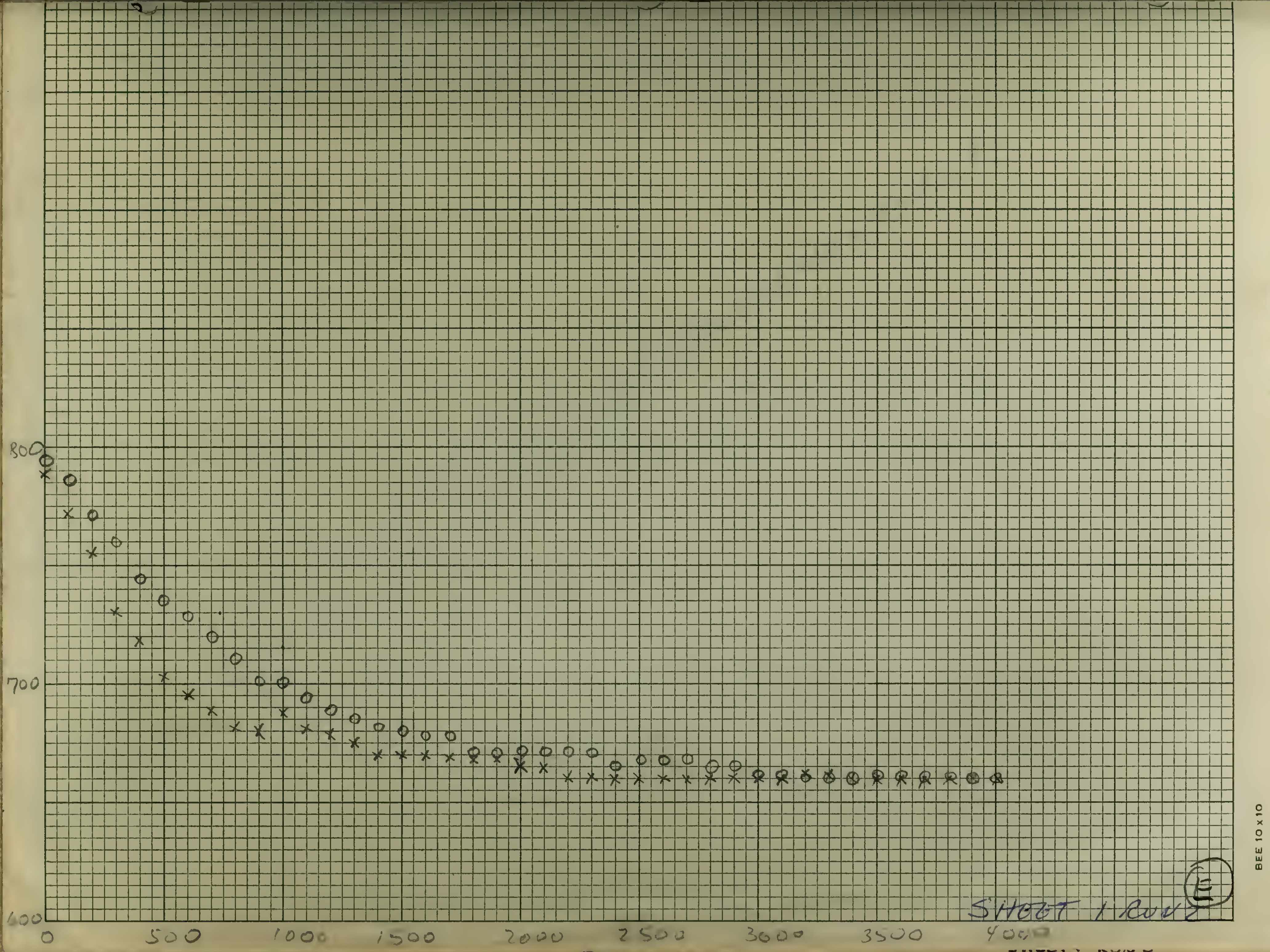
LOAD	B READ			TREAD	
3500	661	660		1690	1695
3600	661	660		1705	1705
3700	661	660		1720	1720
3800	661			1730	
3900	660	660		1749	1750
4000	660			1758	~~1750~~

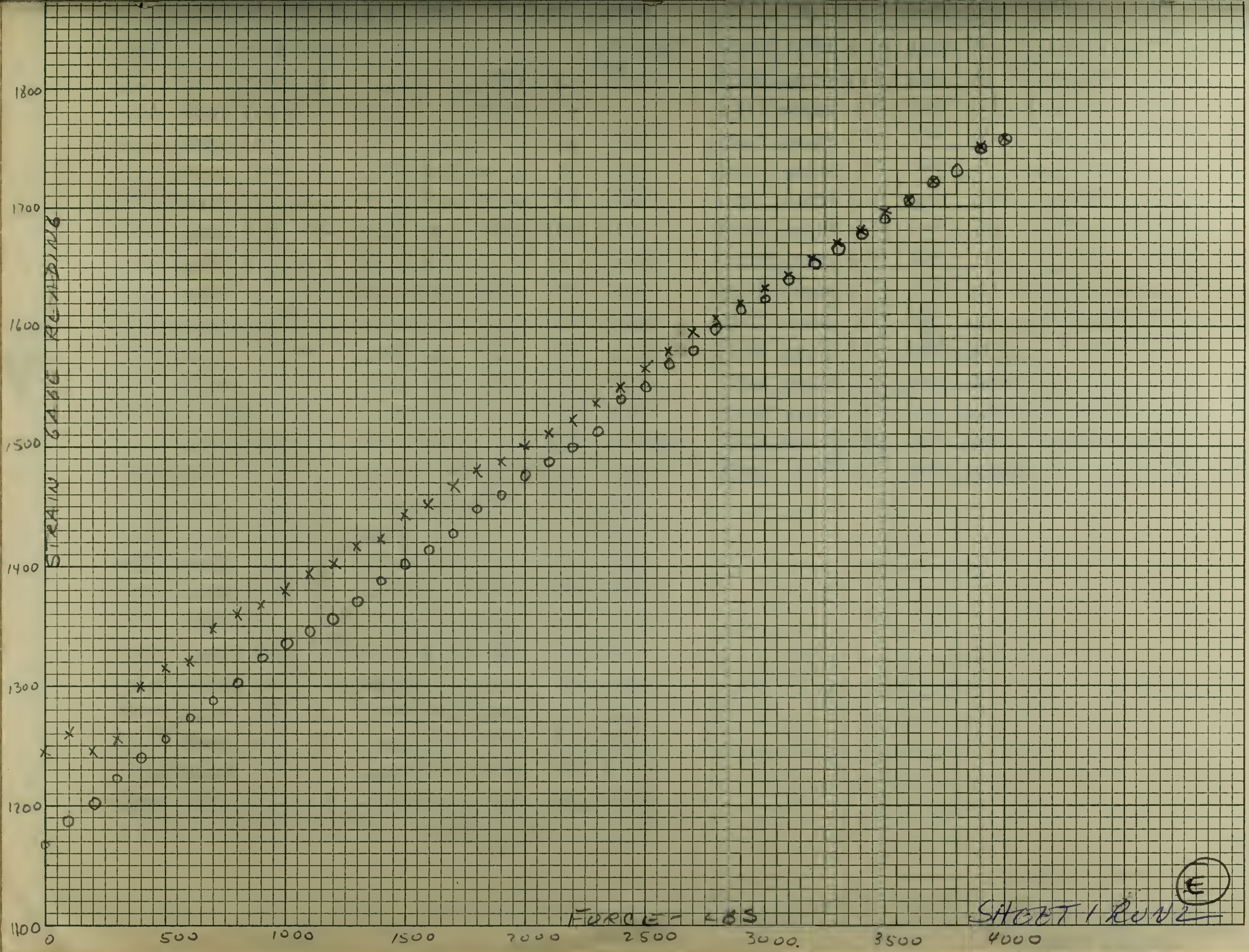
SHEET 1 RUN 2

RP-216

ORIGINAL DATA.

(E)


800
700
600
0
500
1000
1500
2000
2500
3000
3500
4000
SHOT 1 RUN 2
E
BEE 10 x 10



STRAIN GAGE READING
FORCE - LBS
SHEET 1 RUN 2
E
1100
1200
1300
1400
1500
1600
1700
1800
0
500
1000
1500
2000
2500
3000.
3500
4000

BEE 10 x 10

P	$\frac{1}{P}$	B	$B-B_0$	$\frac{1}{\Delta B}$	~~$\frac{\Delta B\,10}{P}$~~	T	ΔT	STRESS
LBS		GAGE	ΔB					~~$\Delta T \times 38.67$~~
0	—	770	0	0		1548	0	$\frac{\Delta B}{P} \times 10^4$
106	.00943	770	0	0		1574	26	
196	.00510	766	4	.25	27.5	1594	46	204.0
298	.00336	759	11	.0909	30.54	1614	66	369.6
395	.00254	748	22	.0455	11.56	1632	84	558.8
500	.00200	738	32	.0313	6.26	1655	107	640.0
597	.00168	727	43	.0233	3.914	1670	122	722.4
696	.00144	715	55	.0182	2.621	1688	140	792.0
797	.00125	708	62	.0161	2.013	1707	159	775.0
899	.00111	701	69	.0145	1.610	1719	171	765.3
994	.00100	699	71	.0141	1.410	1737	189	710.0
1103	.000907	693	77	.0130	1.179	1753	205	698.4
1193	.000838	690	80	.0125	1.048	1766	218	~~633.0~~ 672.4
1296	.000772	688	82	.0122	.9418	1783	235	633.0
1393	.000718	684	86	.0116	.8329	1802	254	617.5
1498	.000668	682	88	.0114	.7615	1819	271	587.8
1594	.000627	680	90	.0111	.6960	1834	286	564.3
1700	.000588	678	92	.0109	.6410	1851	303	541.0
1796	.000557	678	92	.0109	.6071	1865	317	512.4
1898	.000527	675	95	.0105	.5534	1888	340	500.7
2002	.000500	675	95	.0105	.5250	1901	353	475.0
2098	.000476	674	96	.0104	.4950	1919	371	457.0
2197	.000456	673	97	.0103	.4697	1931	383	442.3
2300	.000435	673	97	.0103	.4481	1948	400	422.0
2400	.000417	671	99	.0101	.4212	1964	416	412.8
2502	.000400	670	100	.01	.4000	1980	432	400.0

P	$\frac{1}{P}$	B	$B-B_0$	$\frac{1}{\Delta B}$	~~$\frac{\Delta B}{P}$~~	T	ΔT	$\frac{P}{\text{STRESS}}$
2595	.000386	670	100	.01	.3860	1998	450	386.0 ~~$\Delta T \times 38.67$~~
2705	.000370	670	100	.01	.3700	2014	466	370.0
2817	.000355	670	100	.01	.3550	2030	482	355.
2907	.000344	670	100	.01	.3440	2042	494	344.
3001	.000333	670	100	.01	.3330	2060	512	333.
3104	.000323	670	100	.01	.3230	2071	523	323.
3190	.000313	670	100	.01	.3130	2087	539	313.
3300	.000302	670	100	.01	.3020	2101	553	302.
3403	.000294	670	100	.01	.2940	2120	572	294.
3507	.000285	670	100	.01	.2850	2131	583	285.
3594	.000279	671	~~101~~ 99	.0101	.2818	2147	599	279.
3706	.000270	662	108	.00926	.2500	2162	614	270.2
3798	.000263	665	105	.00952	.2504	2176	628	263.
3902	.000256	666	104	.00961	.2460	2194	646	256.2
3990	.000251	668	102	.00980	.2460	2202	654	256.0

14000

$\frac{\Delta B \cdot 10^4}{P}$: 700, 600, 500, 400, 300, 200, 100, 0

ΔB: 0, 10, 20, 30, 50, 60, 70, 80, 90, 100

SHEET 1 RUN 3.

A.

SHEET 1 RUN 3

A.

FORCE	B LOAD	B UNLOAD	T LOAD	T UNLOAD	FORCE	B LOAD	B UNLOAD	T LOAD	T UNLOAD
0	770	758	1548	1651	2705	670		1014	
106	766		1574		2817	670		1030	
196	759		1594		2907	670		1042	
298	748		1614		3001	670		1060	
395	738		1632		3104	670		1071	
500	727		1655		3188	670		1087	
597	715		1670		3300	670		1101	
696	708		1688		3403	670		1120	
797	701		1707		3507	671		1131	
899	699		1719		3594	671		1147	
994	693		1737		3706	662		1162	
1103	690		1753		3798	665		1176	
1193	688		1766		3902	666		1194	
1296	684		1783		3990?	668		1202 × 38 = 52,000	
1393	682		1802						
1498	680		1819						
1594	678		1834						
1700	678		1851						
1796	675		1865						
1898	675		1888						
2002	674		1901						
2098	673		1918						
2197	673		1931						
2302	671		1948						
2395	670		1964						
2502	670		1980						
2595	670		998						

500
400
48,000

JUMP 1000

ORIGINAL DATA SHEET

(A.)

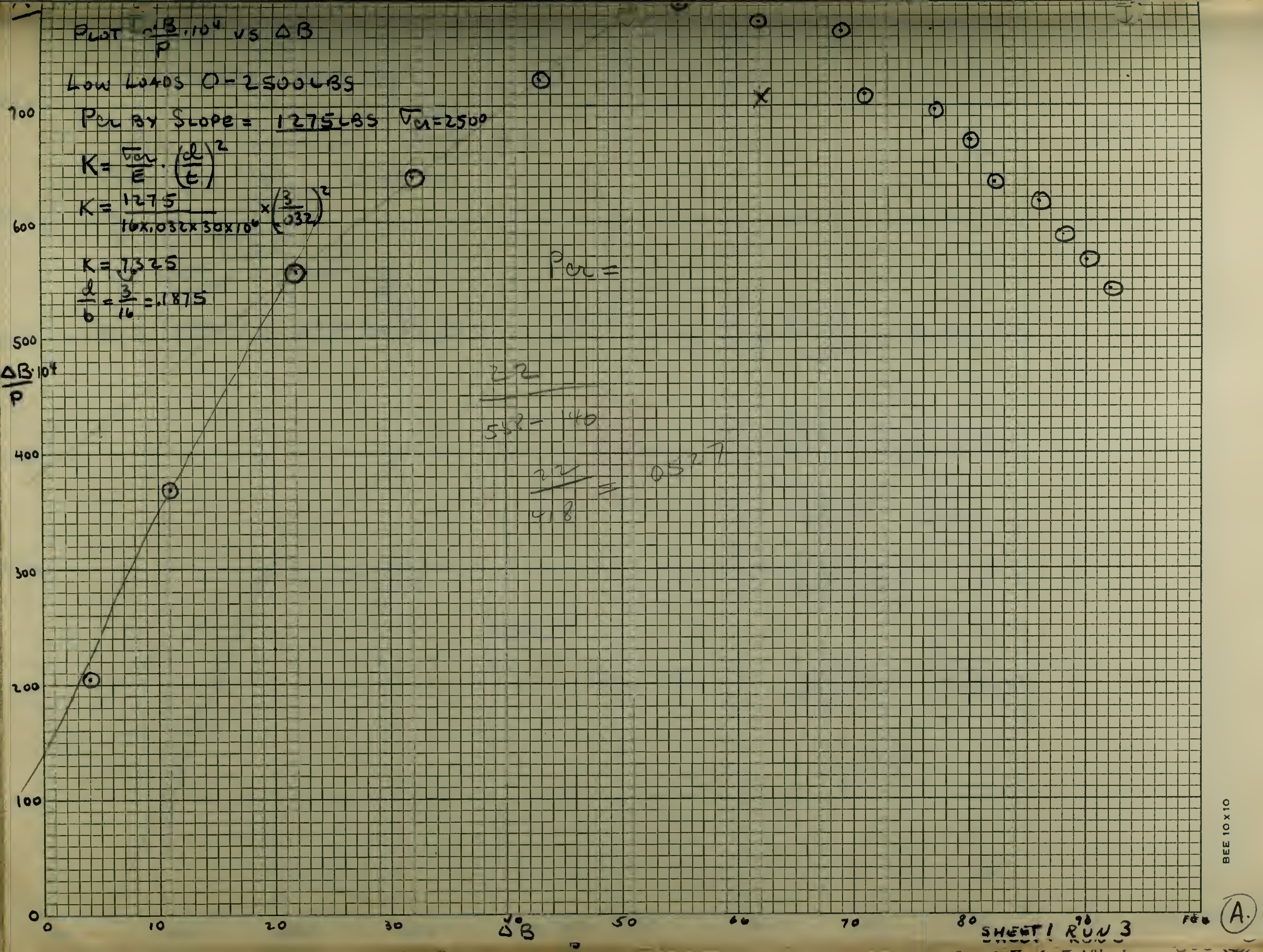
SHEET 1 RUN 3

$\frac{\Delta B \cdot 10^4}{P}$: 0, 100, 200, 300, 400, 500, 600, 700

ΔB: 0, 10, 20, 30, 50, 60, 70, 80, 90, 100

SHEET 1 RUN 3

(A.)



PLOT $\frac{\Delta B}{P} \cdot 10^4$ VS ΔB
LOW LOADS 0-2500 LBS
P_{cr} BY SLOPE = 1275 LBS σ_{cr}=2500
$K = \frac{\sigma_{cr}}{E} \cdot \left(\frac{d}{t}\right)^2$
$K = \frac{1275}{16 \times .032 \times 30 \times 10^6} \times \left(\frac{3}{.032}\right)^2$
K = 7.325
$\frac{d}{b} = \frac{3}{16} = .1875$
P_{cr} =
$\frac{22}{552-140}$
$\frac{22}{418}$ = .0527
$\frac{\Delta B}{P} \cdot 10^4$
ΔB
SHEET 1 RUN 3
BEE 10 X 10
A.

PLOT $\frac{10^4}{P}$ VS $\frac{10^4}{B}$

~~LOW~~ LOADS 300 - 3990

P_{cr} BY INTERCEPT ~~1307~~ 1333 LBS.

$\sigma_{cr} = \frac{P_{cr}}{A} = \frac{1333}{16 \times .032} = \cancel{2550}\ 2602$ PSI

$\frac{\sigma_{cr}}{E} = \left(\frac{t}{d}\right)^2 \left(K\left(\frac{d}{b}\right)\right)$

$K = \frac{\cancel{2602}}{30 \times 10^6} \times \cancel{87.78 \times 10^6}\ 10^3 \times \cancel{\frac{16}{3}}$

$K = \cancel{39{,}700}\ \cancel{40{,}000}\ \cancel{7672}\ .7627$

$\sigma_{cr}\ \frac{1333}{16 \times .032} = 2600$ PSI

$K = \frac{2600}{30 \times 10^6} \times \left(\frac{3}{32 \times 10^{-3}}\right)^2$

$K = \frac{260\cancel{0}}{3\cancel{0}} \times \frac{\cancel{9}\ 3}{1024}$

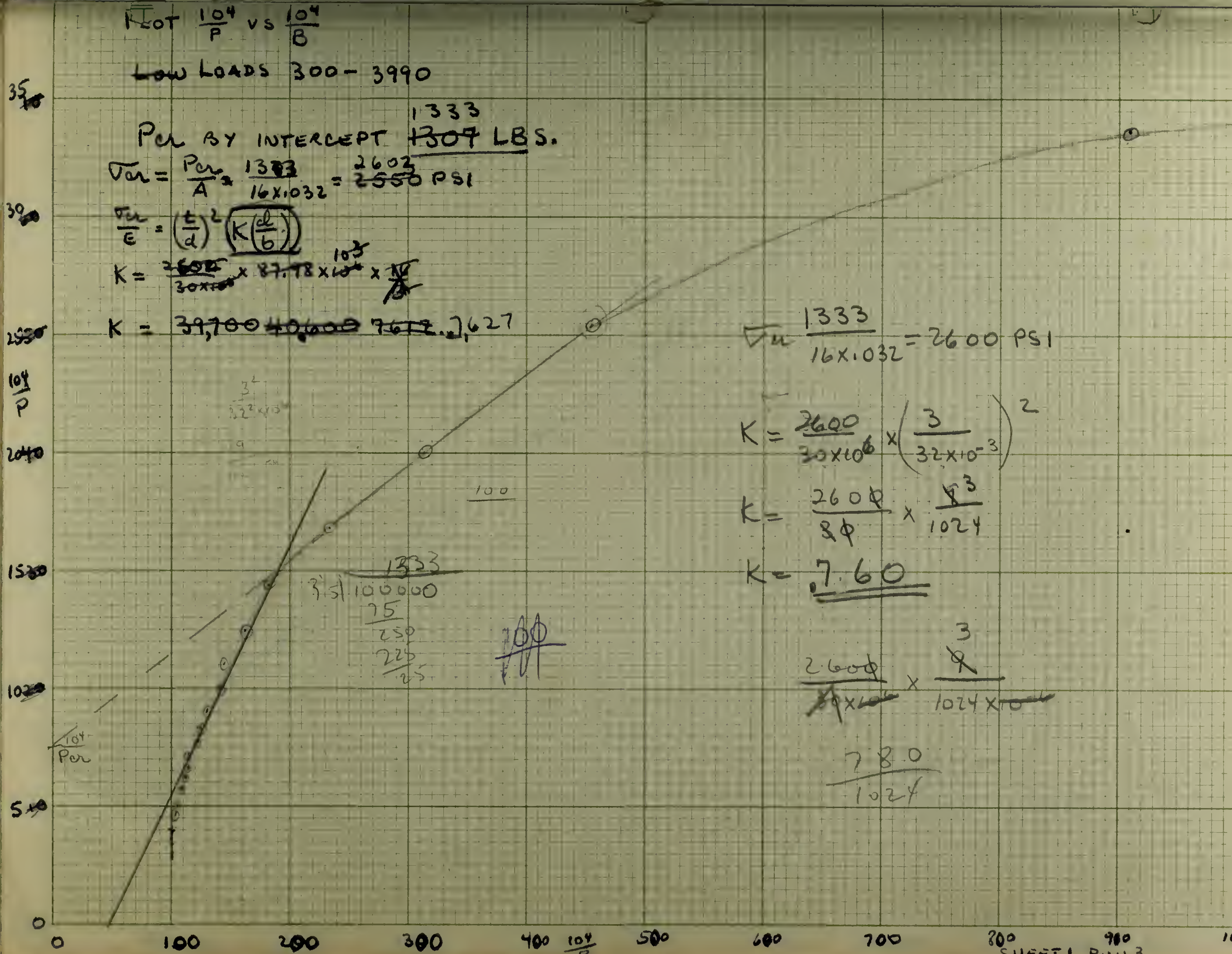
$K = .760$

$\frac{260\cancel{0}}{\cancel{30} \times \cancel{10^6}} \times \frac{\cancel{9}\ 3}{1024 \times \cancel{10^{-6}}}$

$\frac{780}{1024}$

$\frac{1333}{.75)\,100000}$
75
250
225
25

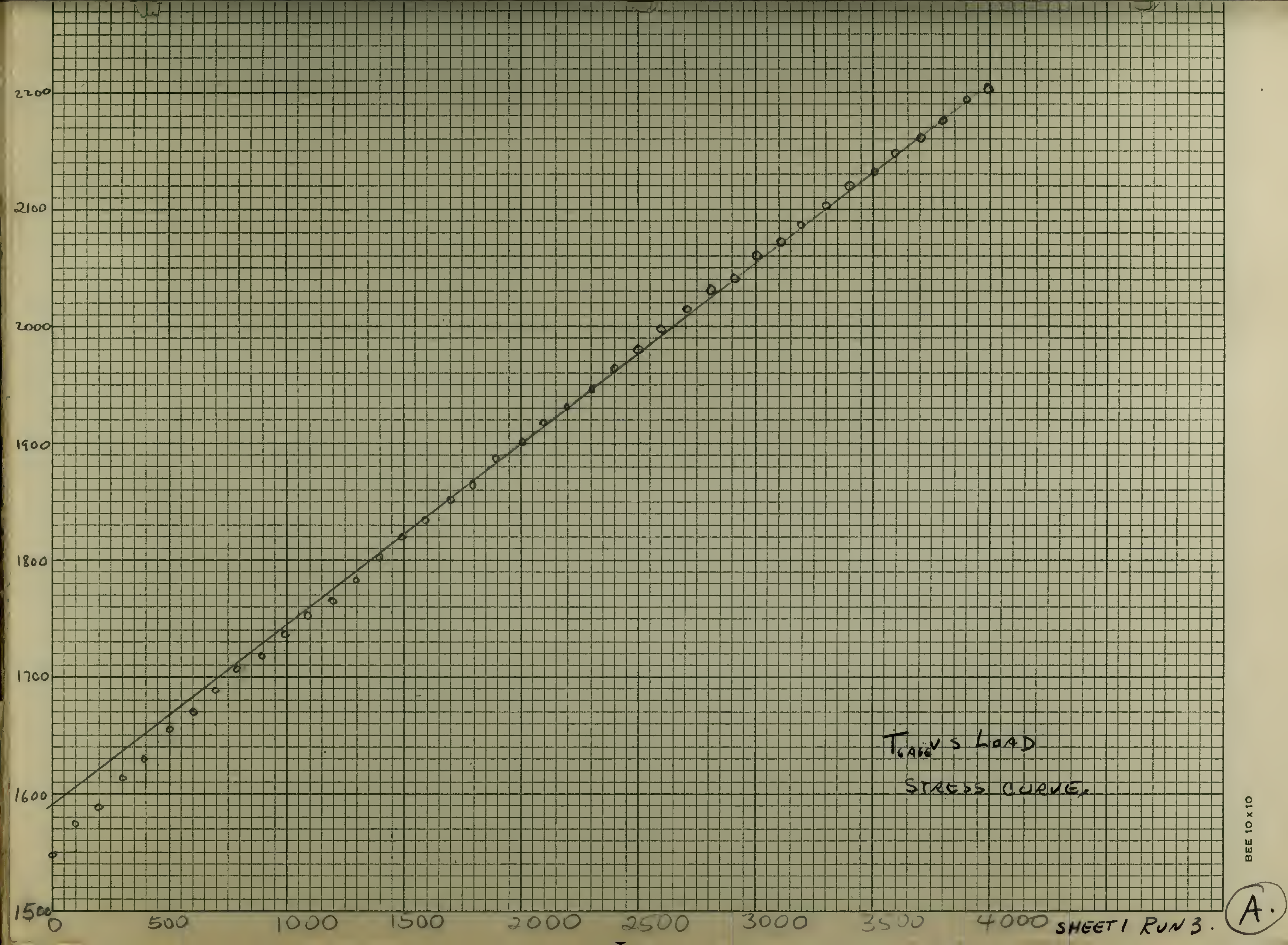
100

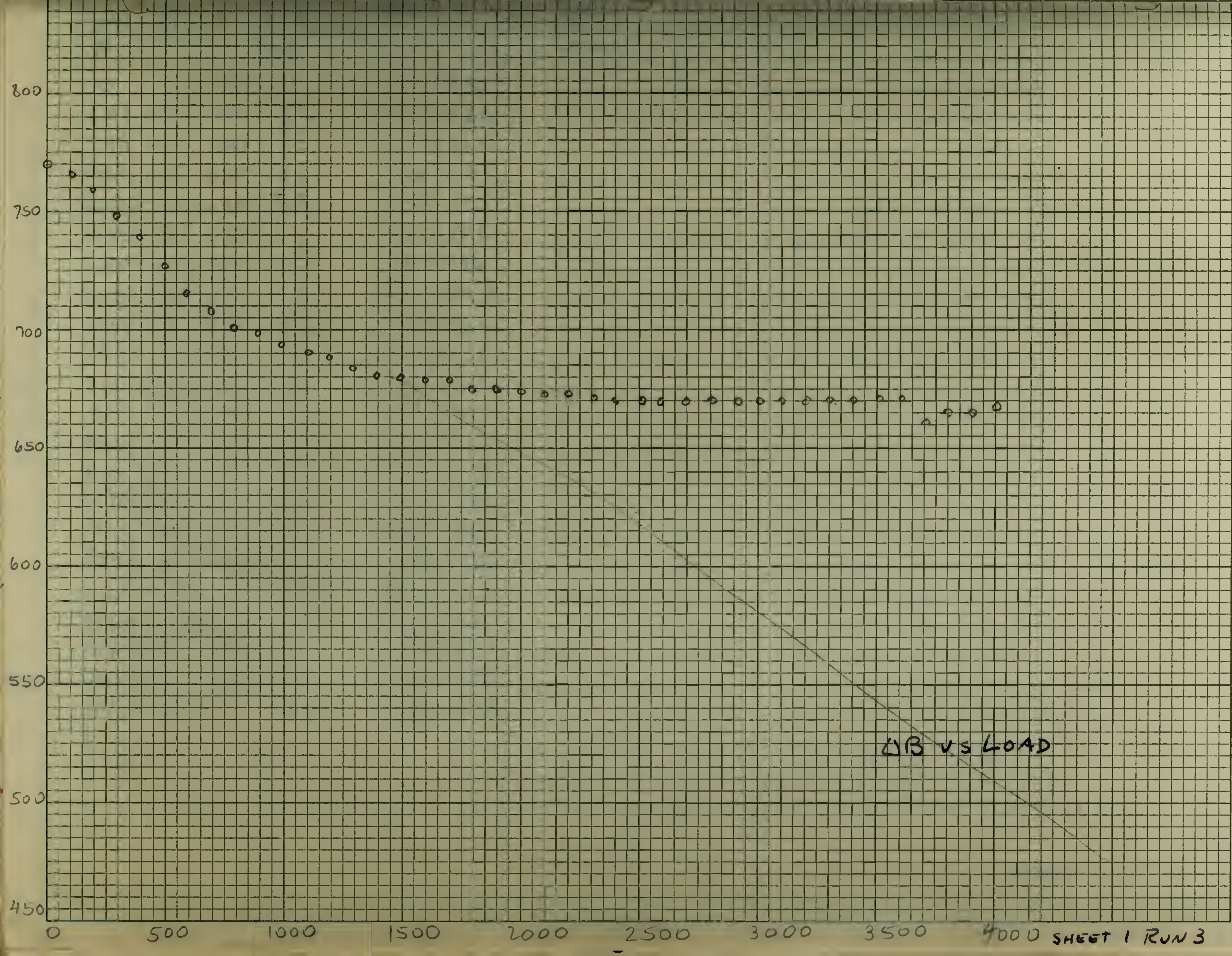


SHEET 1 RUN 3

J. H. WEIL & CO. PHILA. 10 X 10 TO 1 INCH

(A)


T CAGE VS LOAD
STRESS CURVE.
SHEET 1 RUN 3.
A.
BEE 10 x 10
2200
2100
2000
1900
1800
1700
1600
1500
0
500
1000
1500
2000
2500
3000
3500
4000



ΔB vs LOAD
800
750
700
650
600
550
500
450
0
500
1000
1500
2000
2500
3000
3500
4000
SHEET 1 RUN 3
BEE 10x10

LOAD	$10^4/P$	B	$B-B_0$	$\frac{1}{\Delta B}$	$\frac{\Delta B}{P}\times 10^2$	T	ΔT	STRESS PSI
P			ΔB					$\Delta T \times 38.67$
0		774	0		–	489		
502	199	722	52		10.35	582		
998	100	699	75		7.515	662		
1500	667	689	85		5.667	751		
2000	500	684	90		4.500	825		
2505	398	682	92		3.672	902		
3000	333	681	93		3.100	986		
3390	295	681	93		2.743	1043		
3498	286	681	93		2.659	1062		
3995	250	682	92		2.303	1132		
4105	243	685	89		2.168	1167		
4192	238	685	89		2.123	1200		
4508	222	686	88		1.952	1216		
4593	217	688	86		1.872	1230		
4700	213	688	86		1.830	1245		
4808	208	689	85		1.768	1261		
4995	200	690	84		1.682	1292		
5200	192	691	83		1.596	1330		
5408	185	695	79		1.461	1361		
5500	182	696	78		1.418	1377		
5600	179	698	76		1.357	1398		
5775	173	710	64		1.108	1502		

- B-GAGE - READING -

800

700

SHEET 1 RUN 4 F.

- B-GAGE- READING -

FORCE	B LOAD	B UNLOAD	T LOAD	T UNLOAD
0	774	782	489	628
502	722		582	
998	699		662	
1500	689		751	
2000	684		825	
2505	682		902	
3000	681		986	
3390	681		1043	
3498	681		1062	
3995	682		1132	
4105	685		1167	
4192	685		1200	
4508	686		1216	
4593	688		1230	
4700	688		1245	
4808	689		1261	
4995	690		1292	
5200	691		1330	
5408	695		1361	
5500	696		1377	
5600	698		1398	
5775	710		1502	

- ORIGINAL DATA -

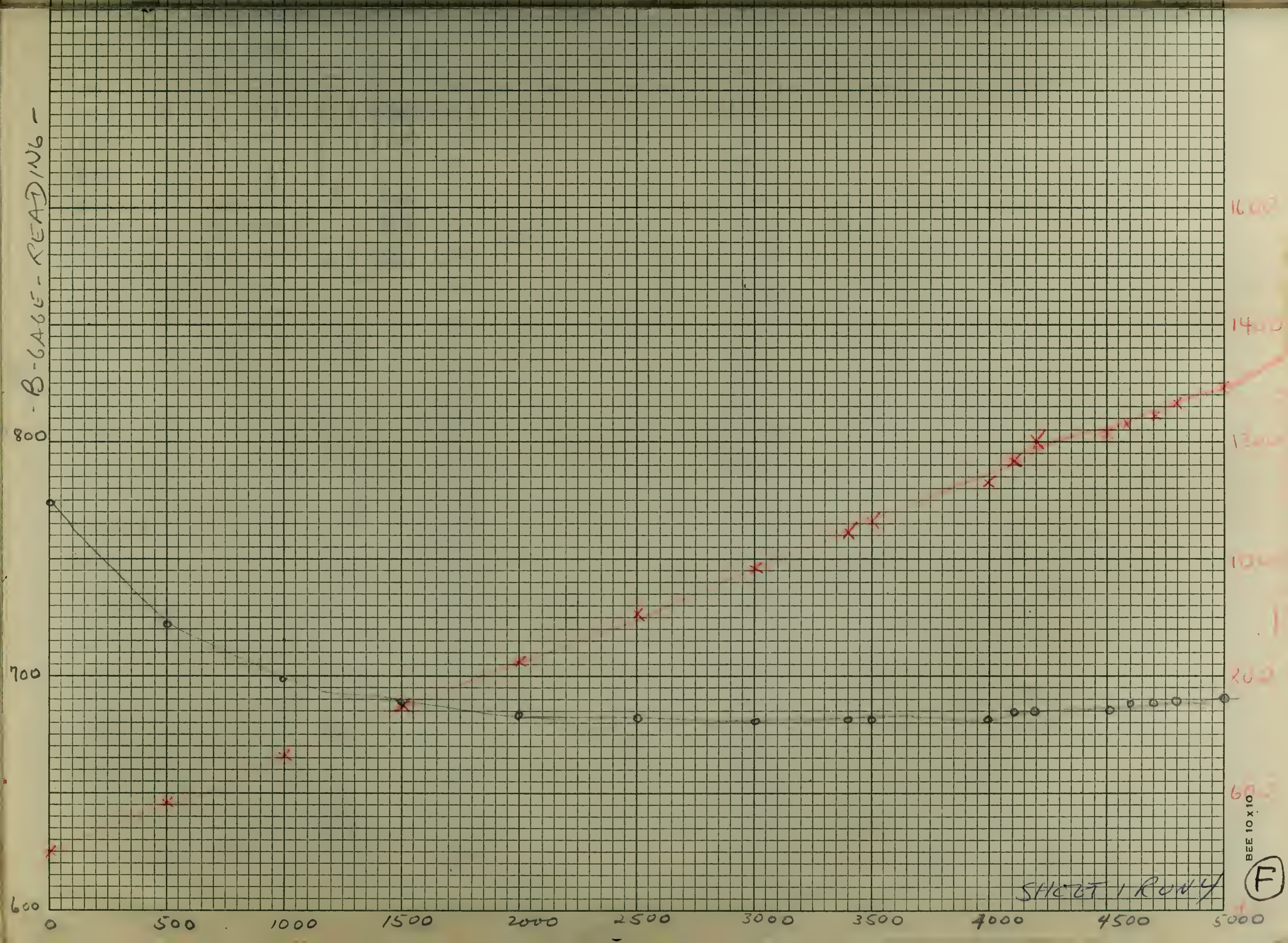
SHEET 1 RUN 4

F

~~SHEET 1 RUN 4~~

800
700
600

0 500 1000 1500 2000 2500 3000 3500 4000 4500 5000


- B-GAGE-READING -
800
700
600
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
1600
1400
BEE 10 x 10
F

LOAD P	$10^4/P$	B-B₀ ΔB	B	$10^3/\Delta B$	~~$\frac{\Delta B}{P} \times 10^2$~~	T	ΔT	STRESS	$\frac{\Delta B}{P} \times 10^2$
0	—	0	512	—	—	1204			—
100	100	14	498	7.14	14.0	1245			14
200	50	22	490	4.54	11.0	1280			11
400	25	43	469	2.33	10.7	1340			10.7
600	16.7	52	460	1.92	7.66	1412			8.67
800	12.5	80	432	1.25	5.40	1479			10.0
1000	10	95	417	1.05	4.17	1542			9.50
1200	8.33	110	402	.909		1610			9.16
1400	7.14	123	389	.813		1668			8.79
1600	6.24	138	374	.724		1731			8.62
1700	5.88	143	369	.699		1772			8.41
1800	5.56	151	361	.662		1815			8.39
1900	5.26	157	355	.636		1848			8.26
2000	5.00	162	350	.617		1882			8.10
2100	4.16	168	344	.595		1920			8.00
2200	4.54	176	336	.568		1950			8.00
2300	4.35	181	331	.552		1985			7.87
2400	4.16	186	326	.537		2024			7.75
2500	4.00	192	320	.521		2060			7.68
2600	3.84	200	312	.500		2100			7.69
2700	3.70	202	310	.495		2132			7.48
2800	3.57	212	300	.472		2170			7.57
2900	3.45	214	298	.467		2208			7.38
3000	3.33	220	292	.455		2245			7.33
3100	3.23	227	285	.441		2290			7.32
3200	3.13	232	280	.431		2322			7.25
3300	3.03	238	274	.420		2360			7.210

SHEET 2 RUN 2

G

Plot of $\frac{\Delta B}{P} \times 10^2$ vs ΔB

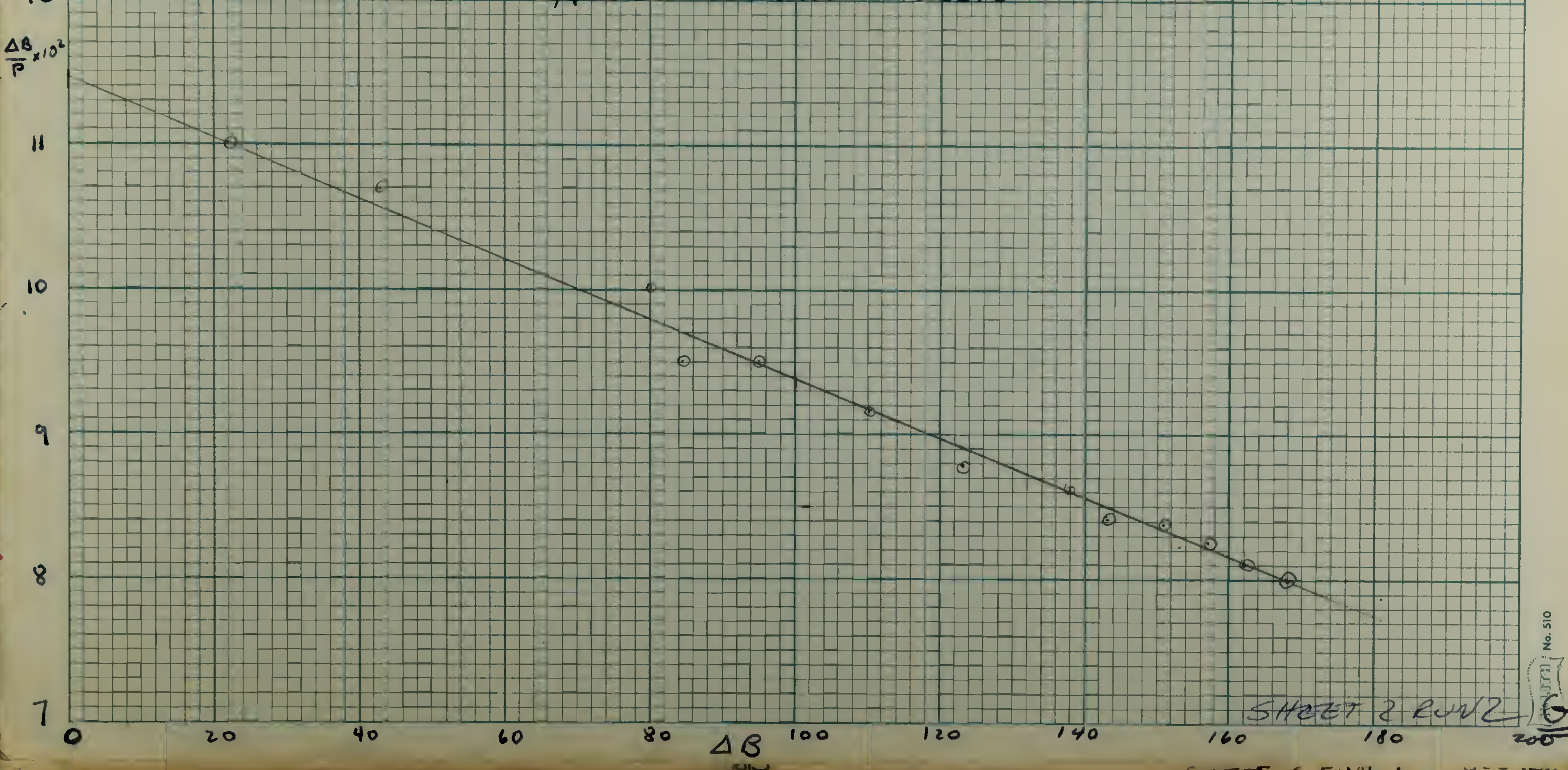
$$P_{cr} = \frac{\Delta B}{\frac{\Delta B}{P} \times 10^2} = \frac{100}{\cancel{-.416}\,(11.46 - 9.38)} = \frac{100 \times 10^2}{-2.08} = -4808\#$$

$$\sigma_{cr} = \frac{-4808}{16 \times .04} = -7513 \text{ PSI}$$

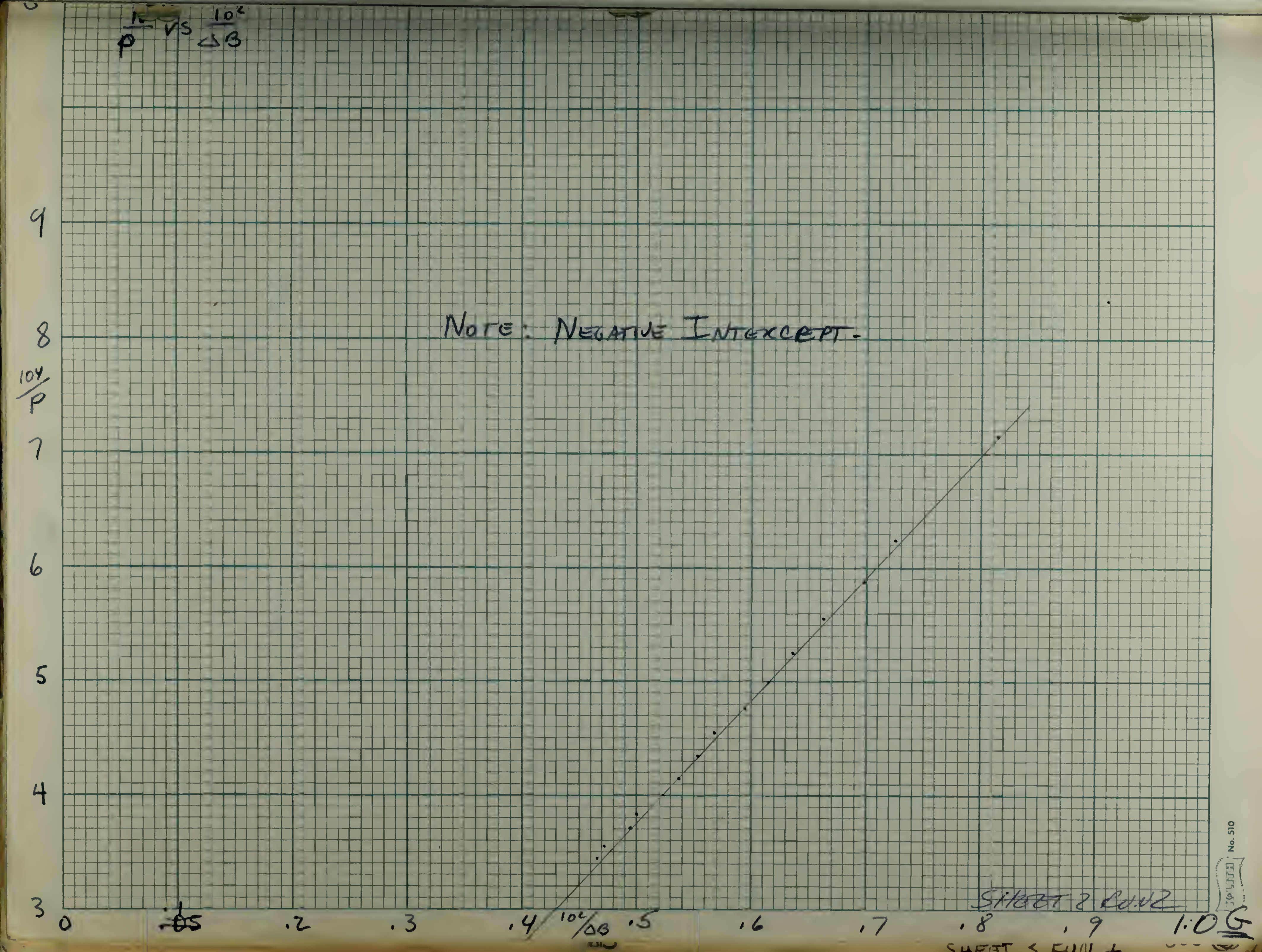
$$K = \frac{\sigma_{cr}}{E} \cdot \left(\frac{d}{t}\right)^2 = \frac{-7513}{10 \times 10^6} \times \frac{3 \cdot 3}{4 \cdot 4 \cdot 10^{-4}} = -7513 \cdot \frac{9}{16} \times 10^{-3}$$

$$K = -4.226$$

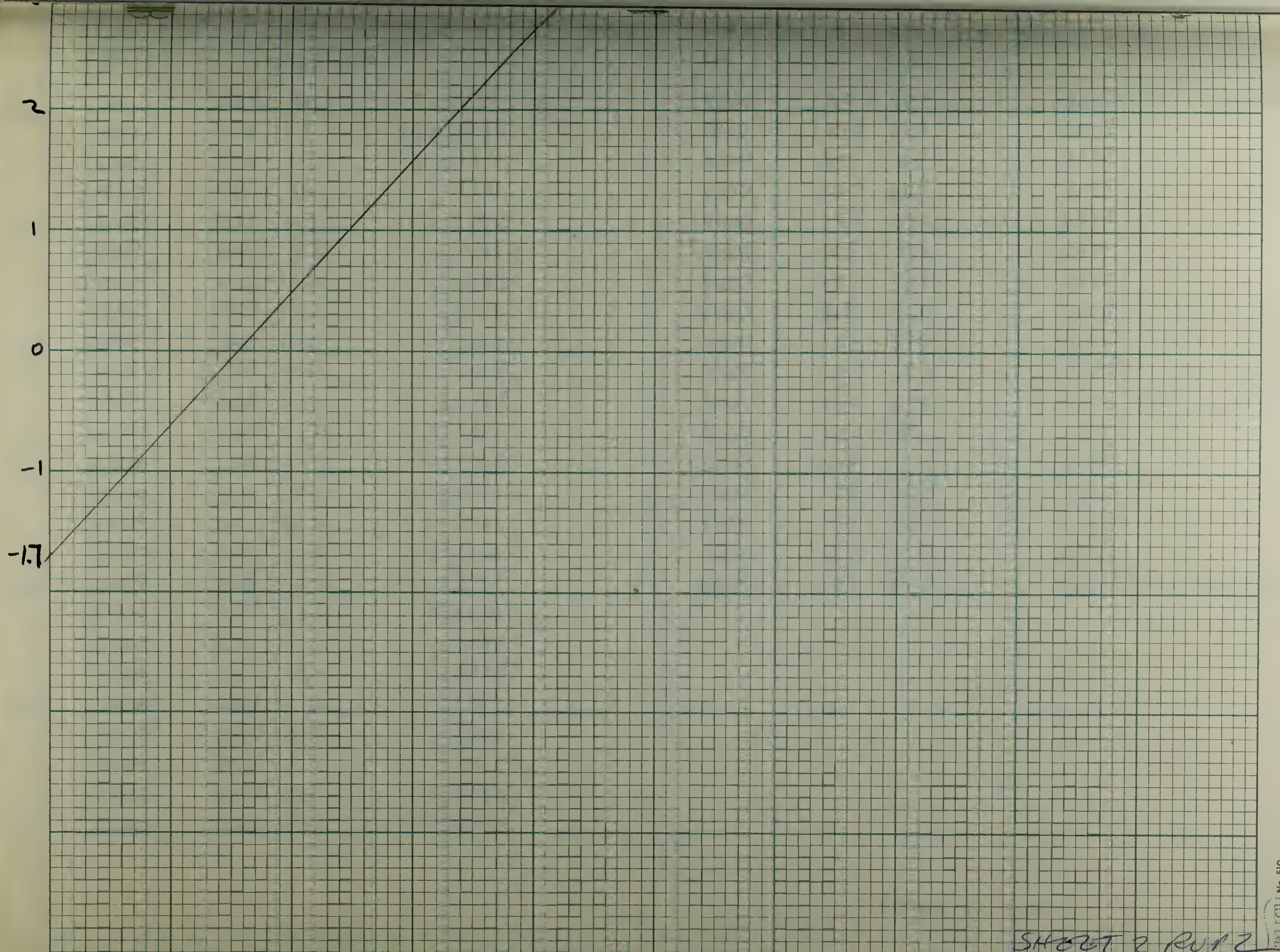
NOTE: NEGATIVE SLOPE



SHEET 2 RUN 2



$\frac{1}{P}$ vs $\frac{10^2}{\Delta B}$
NOTE: NEGATIVE INTERCEPT.
$10^4/P$
3
4
5
6
7
8
9
0
.05
.2
.3
.4
$10^2/\Delta B$
.5
.6
.7
.8
.9
1.0
SHEET 2 CURVE



2
1
0
-1
-1.7
SHEET 2 RUN 2
No. 510

LOAD P	$10^4/P$	B	ΔB B-Bo	$10^2/\Delta B$	$\frac{\Delta B}{P}\times10^4$	T	ΔT	STRESS
0	–	528	0		–	1195	0	–
100		514	14		14.00	1232		
200		501	27		13.5	1271		
400		482	46		11.5	1331		
600		461	67		11.16	1392		
800		440	88		11.00	1461		
1000		422	106		10.6	1529		
1200		408	120		10.0	1592		
1400		390	138		9.86	1662		
1600		380	148		9.25	1728		
1800		362	166		9.22	1795		
2000		350	178		8.90	1860		
2200		338	190		8.64	1928		
2400		323	205		8.54	1996		
2600		312	216		8.31	2061		
2800		300	228		8.14	2130		
3000		288	240		8.00	2195		
3200		278	250		7.81	2270		
3300		271	257		7.79	2302		
3400		262	266		7.82	2338		
3500		258	270		7.71	2379		
3600		250	278		7.72	2422		
3700		245	283		7.65	2469		
3800		240	288		7.58	2522		
3900		232	296		7.59	2572		

LOAD P	$10^4/P$	B	ΔB B-Bo	$10^2/\Delta B$	$\frac{\Delta B}{P}\times10^2$	T	ΔT	S PSI ΔT x 13.3.
4000		224	304			2620	1425	18,952 PSI
4100		218	310			2658		
4200		210	318			2738		
4300		200	328			2779		
4400		195	333			2832		
4500		185	343			2891		
4600		177	351			2949		
4700		168	360			3008		
4800		158	370			3070		
4900		145	383			3138		
5000		134	394			3202	2007	26,693 PSI
5100		122	406			3280		
5200		108	420			3348		
5300		88	440			3420		
5400		75	453			3490		
5500		58	470			3575		
5600		38	490			3650	2455	32,652 PSI

SHEET 2 RUN 3

H

100 0 -100 -200 -300 -400 -500 -600

4500 5000 5500 6000 6500 7000 7500

SHEET 2 RUN 3

24

LOAD LBS	RUN 2 B GAGE READING		T GAGE READING	
0	512	520	1204	1395
100	~~498~~	510	~~1245~~	1416
200	490	500	1280	1440
400	469	479	1340	495
600	460	460	1412	550
800	432	440	1479	602
1000	417	422	1542	660
1200	402	410	1610	719
1400	389	395	1668	774
1600	374	388	1731	838
1700	369	372	1772	868
1800	361	365	1815	898
1900	355	360	1848	924
2000	350	353	1882	955
2100	344	348	1920	990
2200	336	340	1950	1020
2300	331	333	1985	1055
2400	326	330	1024	1080
2500	320	322	1060	1112
2600	312	315	1100	1140
2700	310	310	1132	1172
2800	300	302	1170	1205
2900	298	300	1208	1235
3000	292	293	1245	1270
3100	285	286	1290	1300
3200	280	280	1322	1332
3300	274		1360	

RUN 3 LOAD LBS	B GAGE		T GAGE		LOAD LBS	B GAGE		T GAGE
0	528	552	1195	1225	4000	224	1152	1620 1432
100	514	555	1232	1242	4100	218		1658
200	501		1271		4200	210		1738
400	482		1331		4300	200		1779
600	461		1392		4400	195		1832
800	440		1461		4500	185		1891
1000	422	442	1529	497	4600	177		1949
1200	408		1592		4700	168		1008
1400	390		1662		4800	158	1082	1070 685
1600	380		1728		4900	145		1138
1800	362		1795		5000	134		1202
2000	350	335	1860	816	5100	122		1280
2200	338		1928		5200	108		1348
2400	323		996		5300	1088		1420
2600	312	1282	1061	1005	5400	1075		1490
2800	300		1130		5500	1058		1515
3000	288		1195		5600	1038		1650
3100	27				5700	~~165~~		~~1920~~
3200	278		1270		5800			
3300	271		1302		5900			
3400	262		1338		6000			
3500	258		1379					
3600	250		1422					
3700	245		1469					
3800	240		1522					
3900	232		1572					

– ORIGINAL DATA –

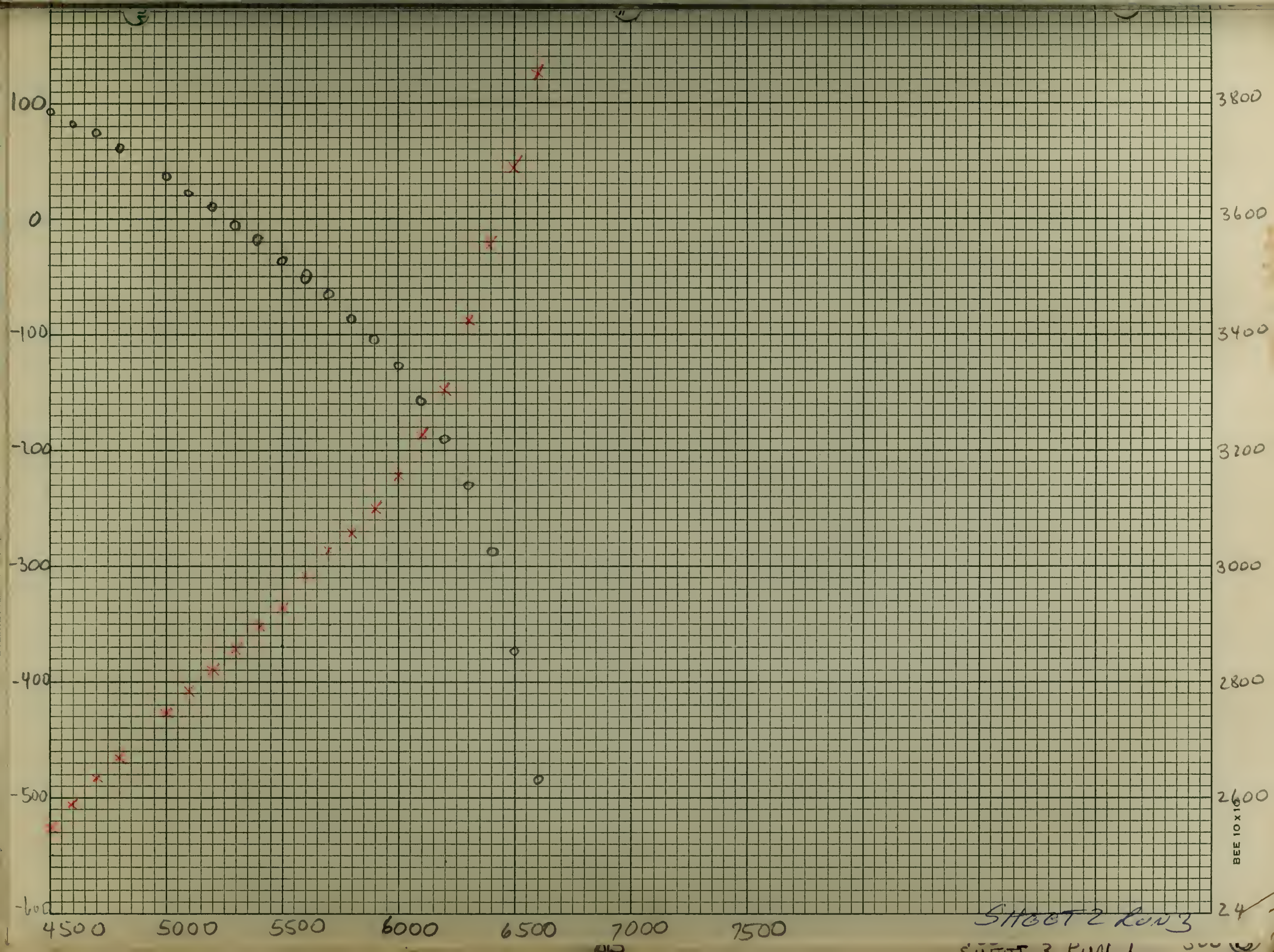
SHEET 2 RUN 3 G-H

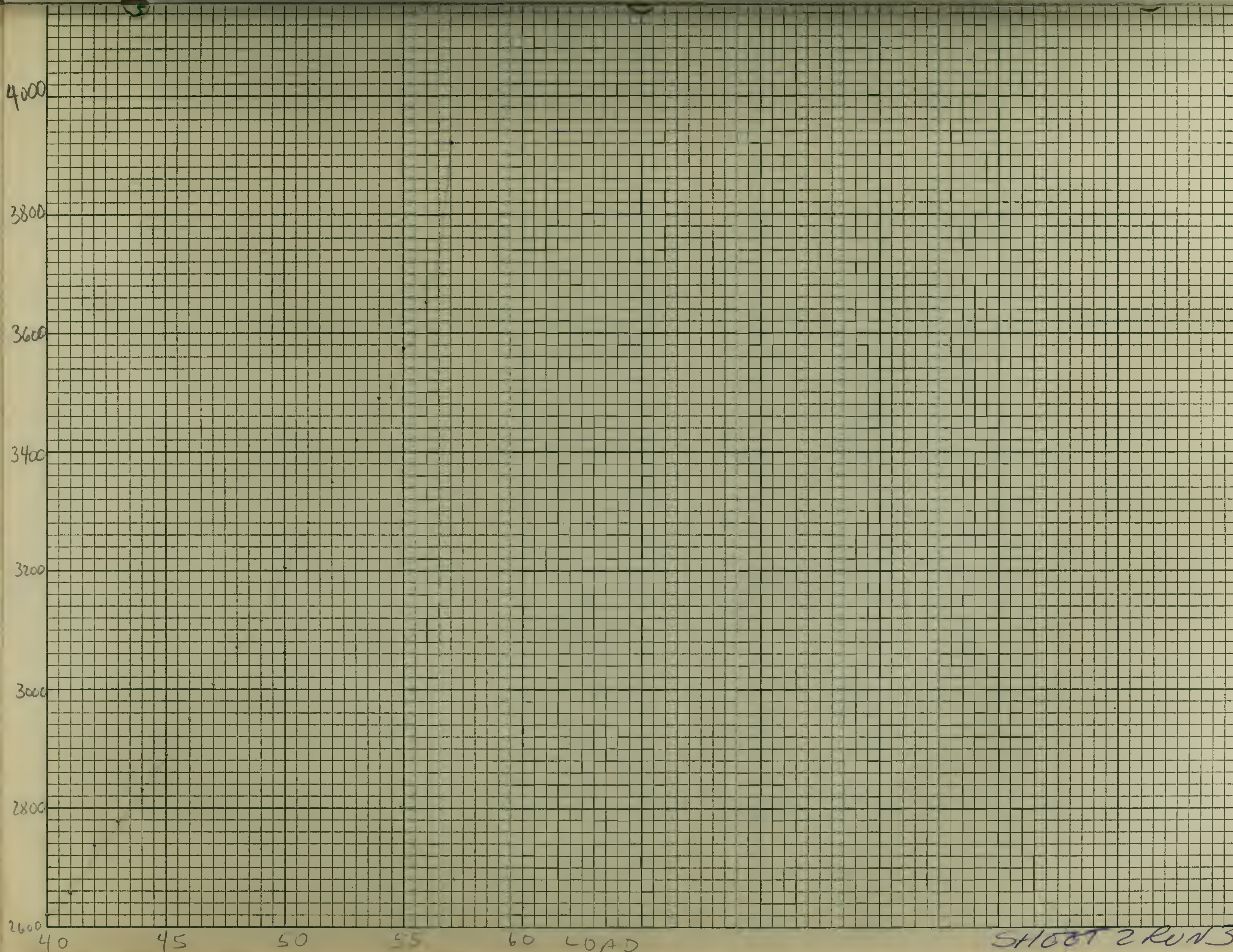
100 0 -100 -200 -300 -400 -500 -600

4500 5000 5500 6000 6500 7000 7500

SHEET 2 RUN 3

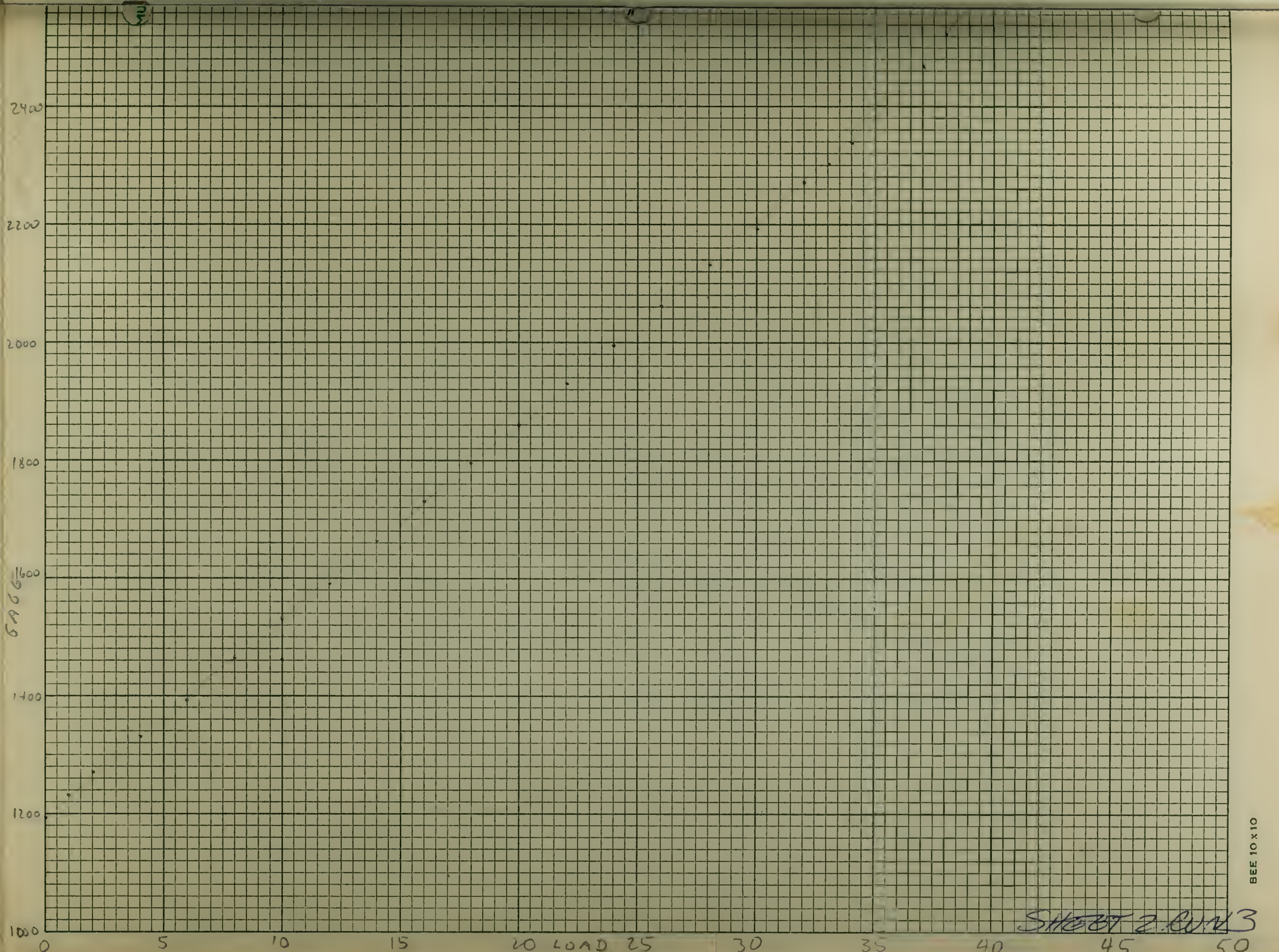
24


100
0
-100
-200
-300
-400
-500
-600
3800
3600
3400
3200
3000
2800
2600
24
BEE 10 X 10
4500
5000
5500
6000
6500
7000
7500
SHOT 2 RUN 3

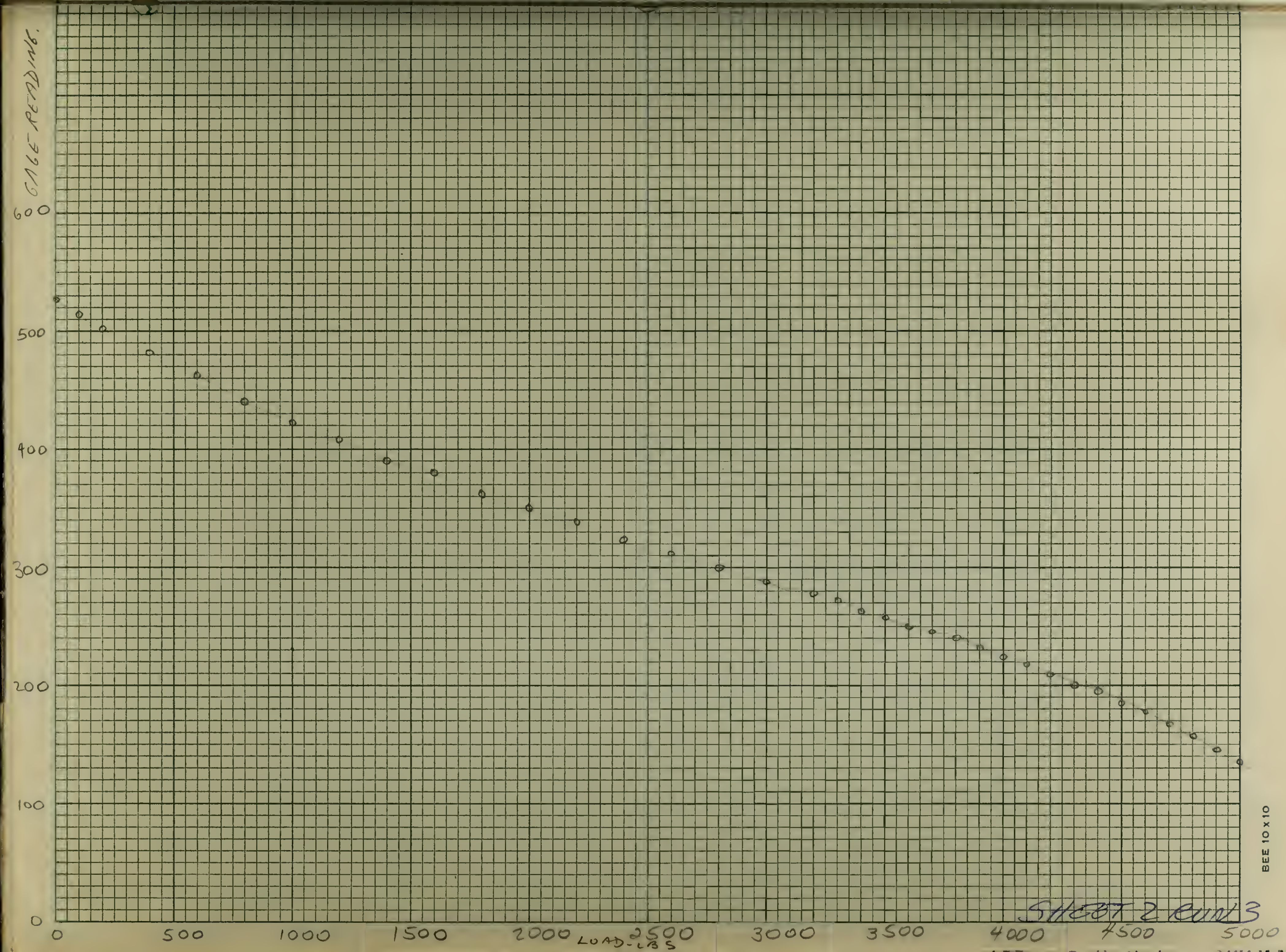


SHEET 2 RUN 3

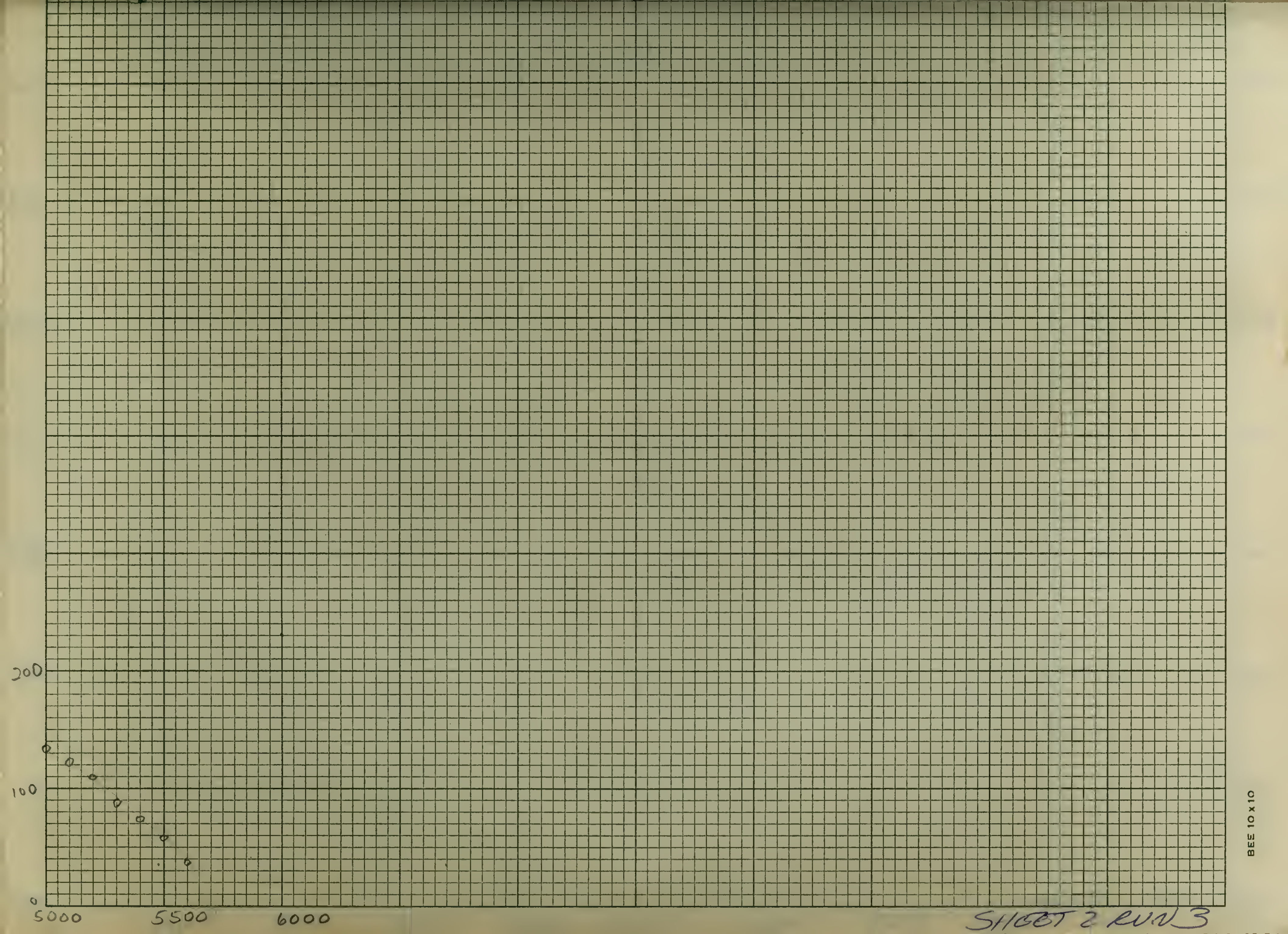
BEE 10 x 10

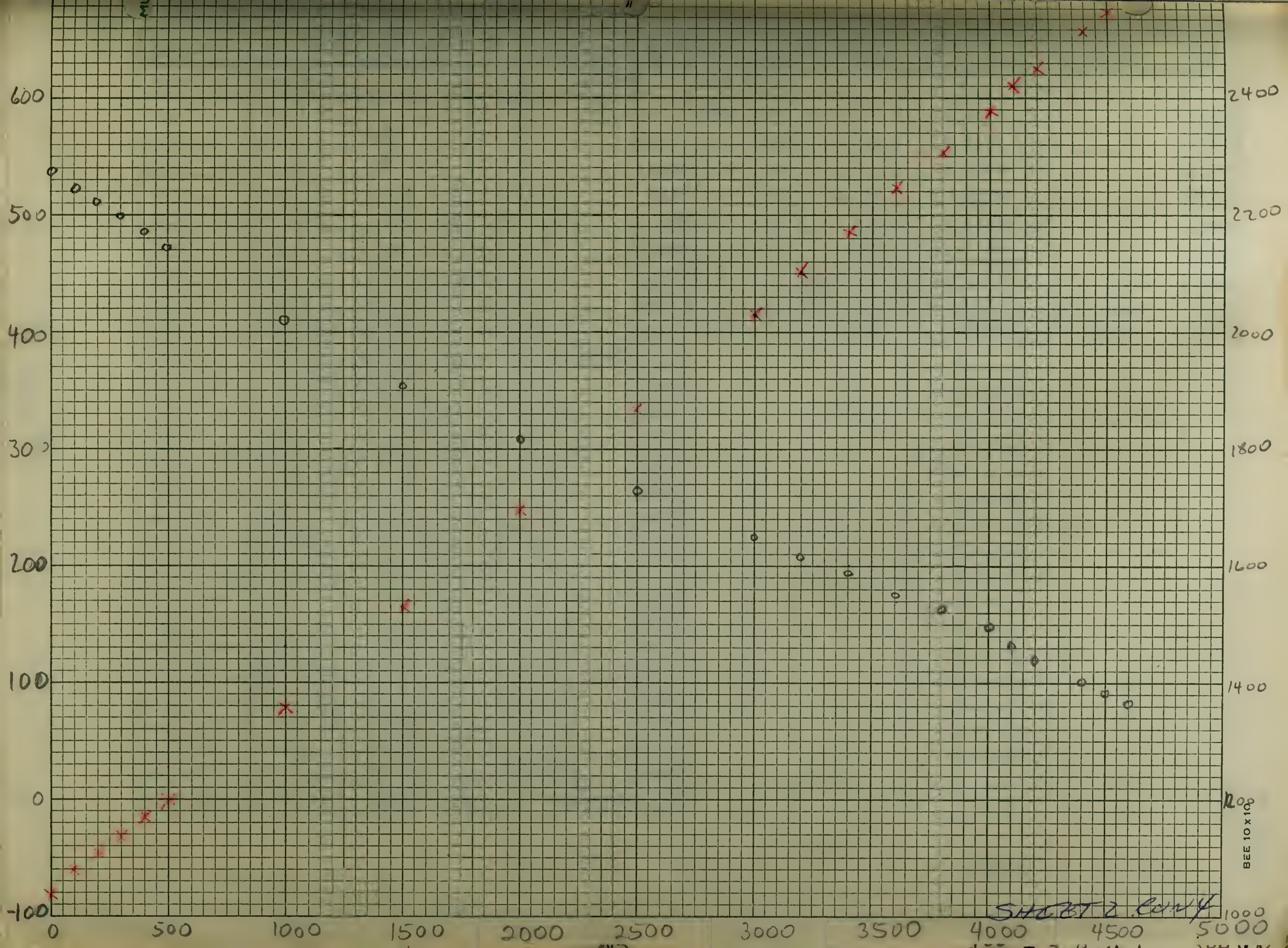


GAGE
2400
2200
2000
1800
1600
1400
1200
1000
0
5
10
15
20 LOAD 25
30
35
40
45
50
SHEET 2 RUN 3
BEE 10 x 10



GAGE READING.
600
500
400
300
200
100
0
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
LOAD-LBS
SHEET 2 RUN 3
BEE 10 x 10


200
100
0
5000
5500
6000
SHEET 2 RUN 3
BEE 10 x 10



600
500
400
30
200
100
0
-100
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
2400
2200
2000
1800
1600
1400
1000
BEE 10 x 10

B ¾ Mn CARBON STEEL 16×36×.032"

DAN'S

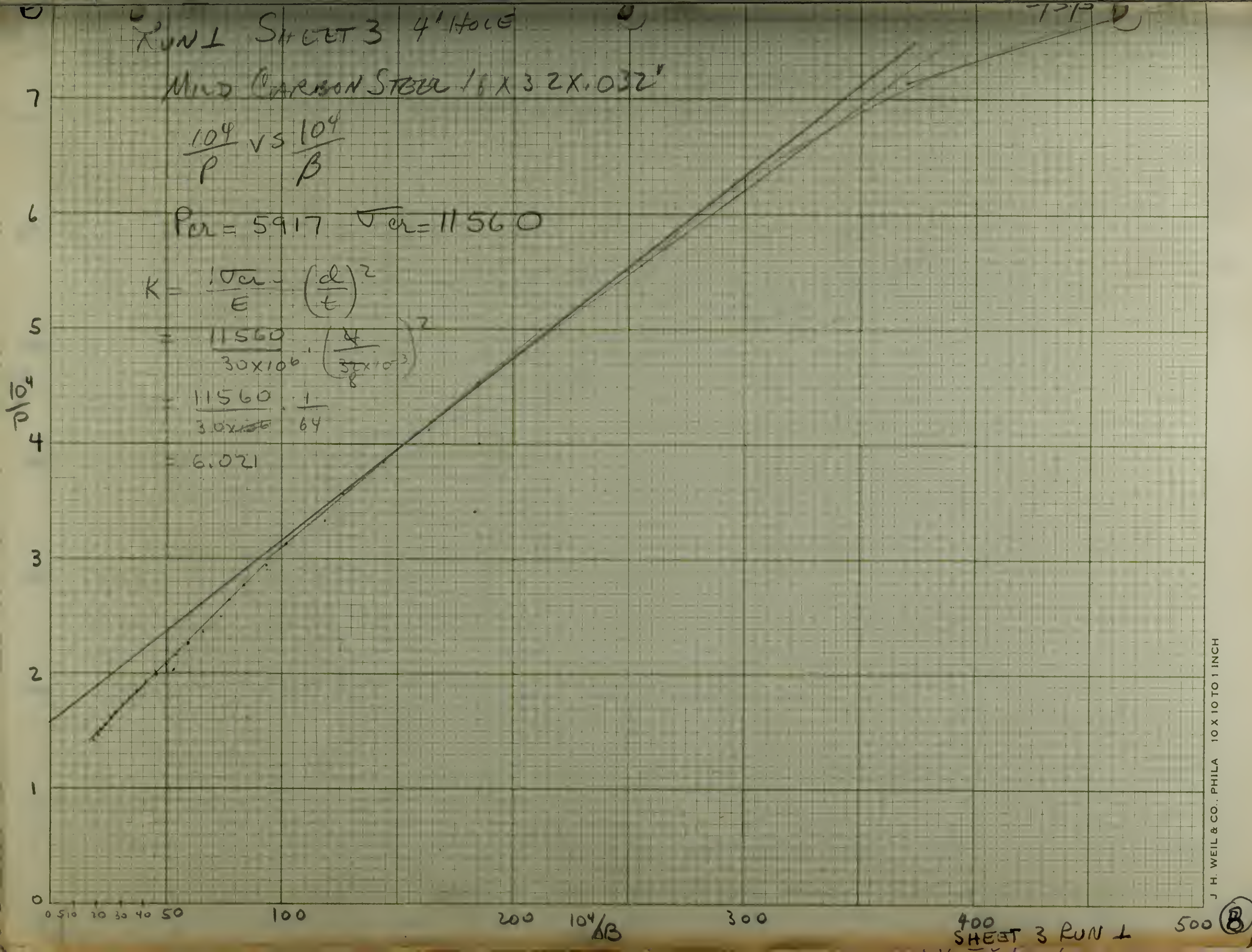
LOAD P	B	B-Bo	$\frac{10^4}{\Delta B}$	$\frac{10^4}{P}$	T	T-To	STRESS PSI	$\frac{\Delta B\, 10^4}{P}$
LBS	GAGE	ΔB					ΔT×38.67	
0	1361	0	—	—	1209	0	—	
200	1360	1	104	50	1260	51		50.00
400	1360	1	104	25	1302	93		25.00
600	1365	5	2000	16.7	1345	136		83.33
800	1370	9	1111	12.5	1389	180		112.50
1000	1372	11	909	10	1430	221		110.0
1200	1380	19	526	8.33	1465	256		158.33
1400	1388	27	370	7.14	1510	301		192.9
1600	1395	34	294	6.25	1542	333		212.5
1800	1400	39	256	5.55	1595	386	14950	216.7
2000	1408	47	212	5	1632	423		235.0
2200	1415	54	185	4.54	1662	453		245.5
2400	1422	61	163	4.16	1692	483		254.1
2600	1431	70	143	3.84	1722	513		269.2
2800	1440	79	127	3.57	1758	543		282.1
3000	1445	84	119	3.33	1780	571		280.0
3200	1459	98	102	3.12	1812	603		306.2
3400	1469	108	93	2.94	1841	632		317.6
3600	1480	119	84	2.78	1871	662		330.6
3800	1490	129	77.5	2.63	1900	691		339.5
4000	1505	134	74.6	2.5	1931	722		335.0
4200	1521	150	66.6	2.38	1960	751		357.1
4400	1540	169	59.1	2.27	1999	790		384.1
4600	1554	183	54.6	2.17	2023	814		397.8
4800	1570	199	50.3	2.08	2050	841		414.6
5000	1591	220	45.4	2	2079	870		440.0
5200	1612	241	41.4	1.92	2109	900	34,800	463.5

LOAD P	B GAGE	B-Bo	$\frac{10^3}{\Delta B}$	$\frac{10^4}{P}$	T	T-To	STRESS PSI		$\frac{\Delta B}{P}$
LBS	Bo 1361					To 1209			
5400	1629	268	37.3	1.85	2140	931			496.3
5600	1655	294	34.0	1.79	2169	960			525.0
5800	1680	319	31.3	1.72	2200	991			550.0
6000	1715	354	28.2	1.67	2230	1021			590.0
6200	1748	387	25.8	1.61	2260	1051			624.2
6400	1780	419	23.9	1.56	2290	1081			654.7
6600	1815	454	22.0	1.51	2325	1116			687.9
6800	1852	491	20.4	1.47	2355	1146	44,400		722.1
7000	1892	531	18.7	1.43	2392	1183	45,800		715.7

ORIGINAL DATA SHEET

SHEET 3 RUN 1

B


RUN 1 SHEET 3 4' HOLE
MILD CARBON STEEL 16 X 32 X .032"
$\frac{10^4}{P}$ VS $\frac{10^4}{\beta}$
P_{cr} = 5917 σ_{cr} = 11560
$K = \frac{\sigma_{cr}}{E}\left(\frac{d}{t}\right)^2$
$= \frac{11560}{30\times10^6}\cdot\left(\frac{4}{\frac{32}{8}\times10^{-3}}\right)^2$
$= \frac{11560}{30\times10^6}\cdot\frac{1}{64}$
= 6.021
$10^4/P$
$10^4/\Delta B$
0 5 10 20 30 40 50 100 200 300 400 500
0 1 2 3 4 5 6 7
J. H. WEIL & CO., PHILA 10 X 10 TO 1 INCH
SHEET 3 RUN 1
8

CHANGE IN SLOPE
120
130
140
150
160
170
180
190
200
J. H WEIL & CO., PHILA 10 X 10

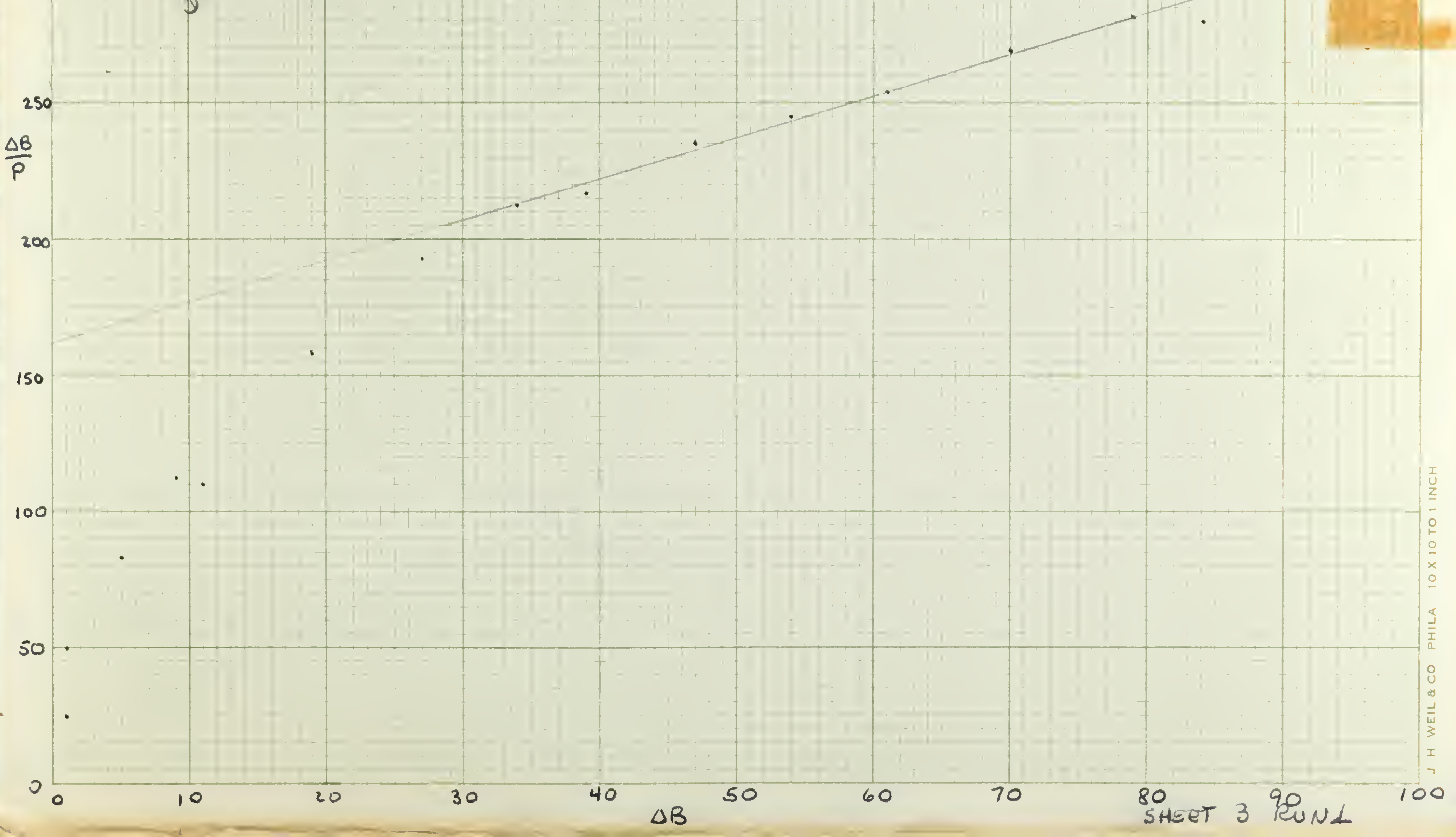
B. SHEET 3 RUN 1. MILD CARBON STEEL 16 X 36 X .032 4 HOLE.

PLOT $\frac{\Delta B}{P} \times 10^4$ VS ΔB. TO FIND P_{cr} BY SLOPE METHOD.

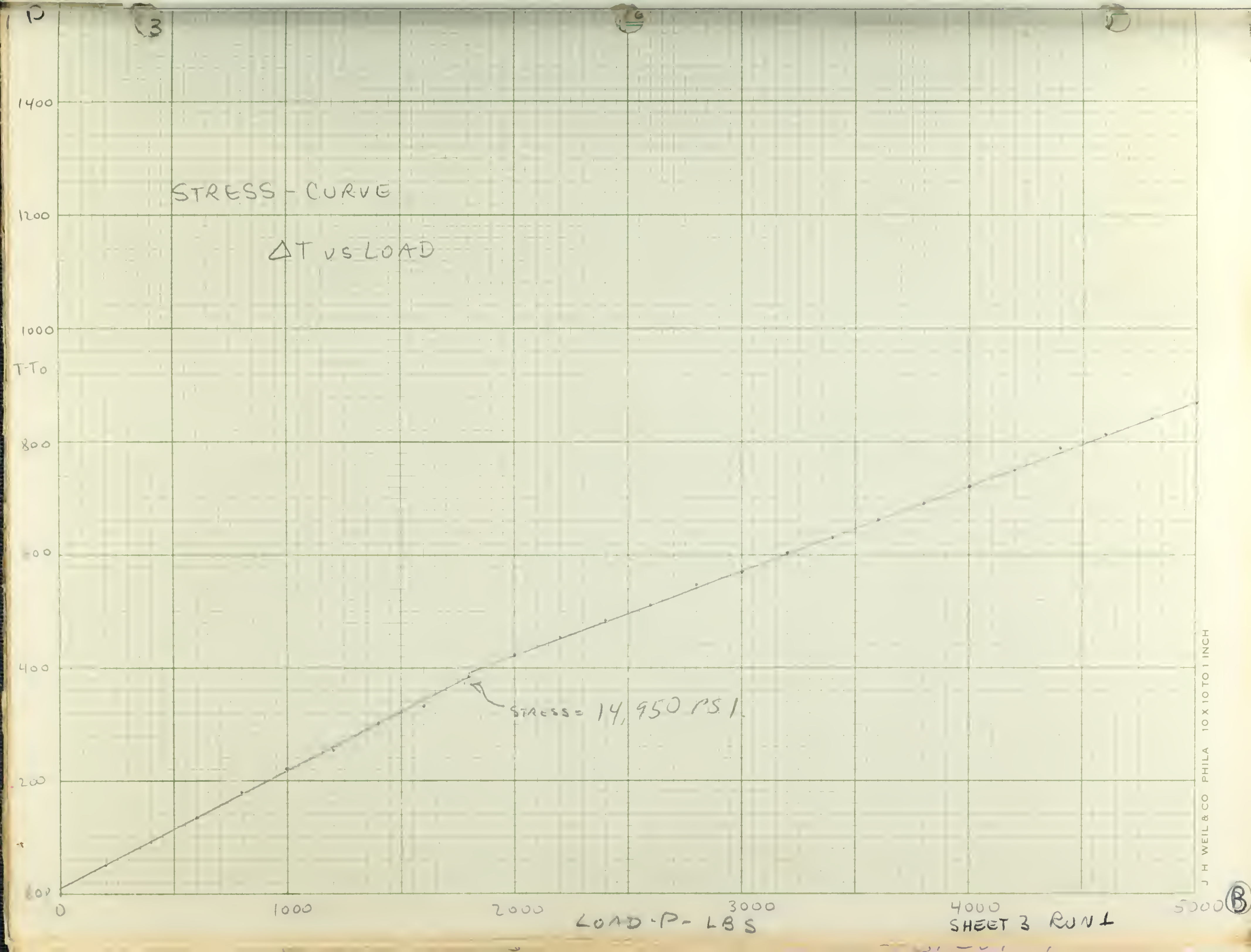
$P_{cr} = 6660 \quad \sigma_{cr} = 13006$ PSI.

$K = \frac{\sigma_{cr}}{E}\left(\frac{d}{t}\right)^2 = 6.773.$

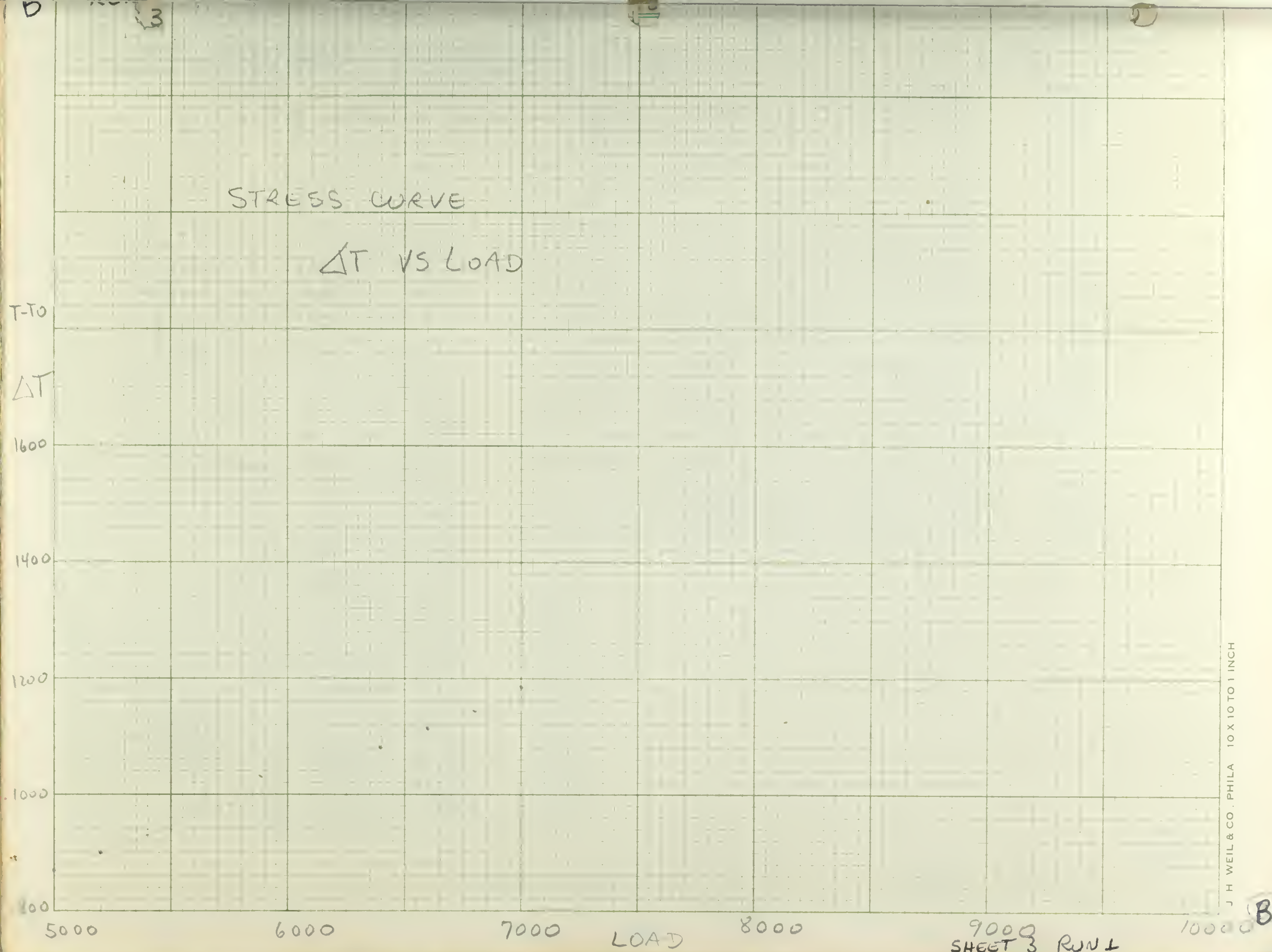
$\frac{13006}{30 \times 10^6} \times \frac{16}{1024 \times 10^{-6}} = 6.773$



SHEET 3 RUN 1 B



STRESS-CURVE
ΔT vs LOAD
T-To
1400
1200
1000
800
400
200
0
1000
2000
3000
4000
5000
STRESS = 14,950 PSI
LOAD-P-LBS
SHEET 3 RUN 1
J H WEIL & CO PHILA 10 X 10 TO 1 INCH


STRESS CURVE
ΔT VS LOAD
T-TO
ΔT
1600
1400
1200
1000
800
5000
6000
7000
LOAD
8000
9000
10000
J H WEIL & CO. PHILA 10 X 10 TO 1 INCH

SHEET 3 RUN 1

(C) SHEET 3 RUN 2 4" HOLE

LOAD P	$10^4/P$	B	B-B₀ ΔB	$10^4/\Delta B$	T	T-T₀ ΔT	STRESS ΔT×38.67	$\frac{\Delta B}{P}\times10^2$
0	—	1272	0	—	1510	0	0	
200	50	1272	0	—	1531	21	—	
400	25	1276	4	2500	1562	52		1.00
600	16.7	1280	8	1250	1598	88		1.33
800	12.5	1288	16	625	1637	127		2.00
1000	10	1295	23	435	1675	165		2.30
1200	8.33	1302	30	333	1711	201		2.50
1400	7.14	1310	38	263	1744	234		2.71
1600	6.25	1318	46	217	1772	262		2.88
1800	5.56	1325	53	189	1804	294		2.94
2000	5	1335	63	159	1839	329		3.15
2200	4.55	1343	71	141	1868	358		3.23
2400	4.16	1352	80	125	1895	385		3.33
2600	3.85	1361	89	112	1925	415		3.46
2800	3.57	1372	100	100	1955	445		3.57
3000	3.33	1382	110	90.9	1980	470		3.67
3200	3.13	1394	122	82.0	2004	494		3.81
3400	2.94	1402	130	76.9	2034	524		3.82
3600	2.78	1418	146	68.5	2063	553		4.06
3800	2.63	1432	160	62.5	2091	581		4.21
4000	2.50	1445	173	57.8	2118	608		4.33
4200	2.38	1462	190	52.6	2146	636		4.52
4400	2.27	1479	207	48.3	2174	664		4.70
4600	2.17	1496	224	44.6	2200	690		4.87
4800	2.08	1518	246	40.7	2229	719		5.13

LOAD P	$10^4/P$	B	B-B₀	$10^4/\Delta B$	T	T-T₀ ΔT	STRESS ΔT×38.67	$\frac{\Delta B}{P}$
5000	2	1539	267	37.5	2258	748		5.34
5200	1.92	1562	290	34.4	2285	775		5.58
5400	1.85	1589	317	31.5	2315	805		5.87
5600	1.78	1612	340	29.4	2340	830		6.07
5800	1.72	1649	379	26.4	2372	862		6.53
6000	1.67	1672	402	24.9	2400	890		6.70
6200	1.61	1702	432	23.1	2422	912		6.97
6400	1.56	1735	465	21.5	2450	940		7.27
6600	1.52	1770	498	20.1	2479	969		7.55
6800	1.47	1805	533	18.8	2502	992		7.84
7000	1.43	1845	563	17.8	2532	1022		8.04
7200	1.39	1882	610	16.4	2560	1050	40,360 PSI	8.47
7400	1.35	1922	650	15.4	2592	1082		8.78
7600	1.32	1961	689	14.5	2625	1115		9.07
7800	1.28	2028	756	13.2	2681	1171		9.69
8000	1.25	2062	790	12.7	2712	1202		9.88

ORIGINAL DATA SHEET

SHEET 3 RUN 2

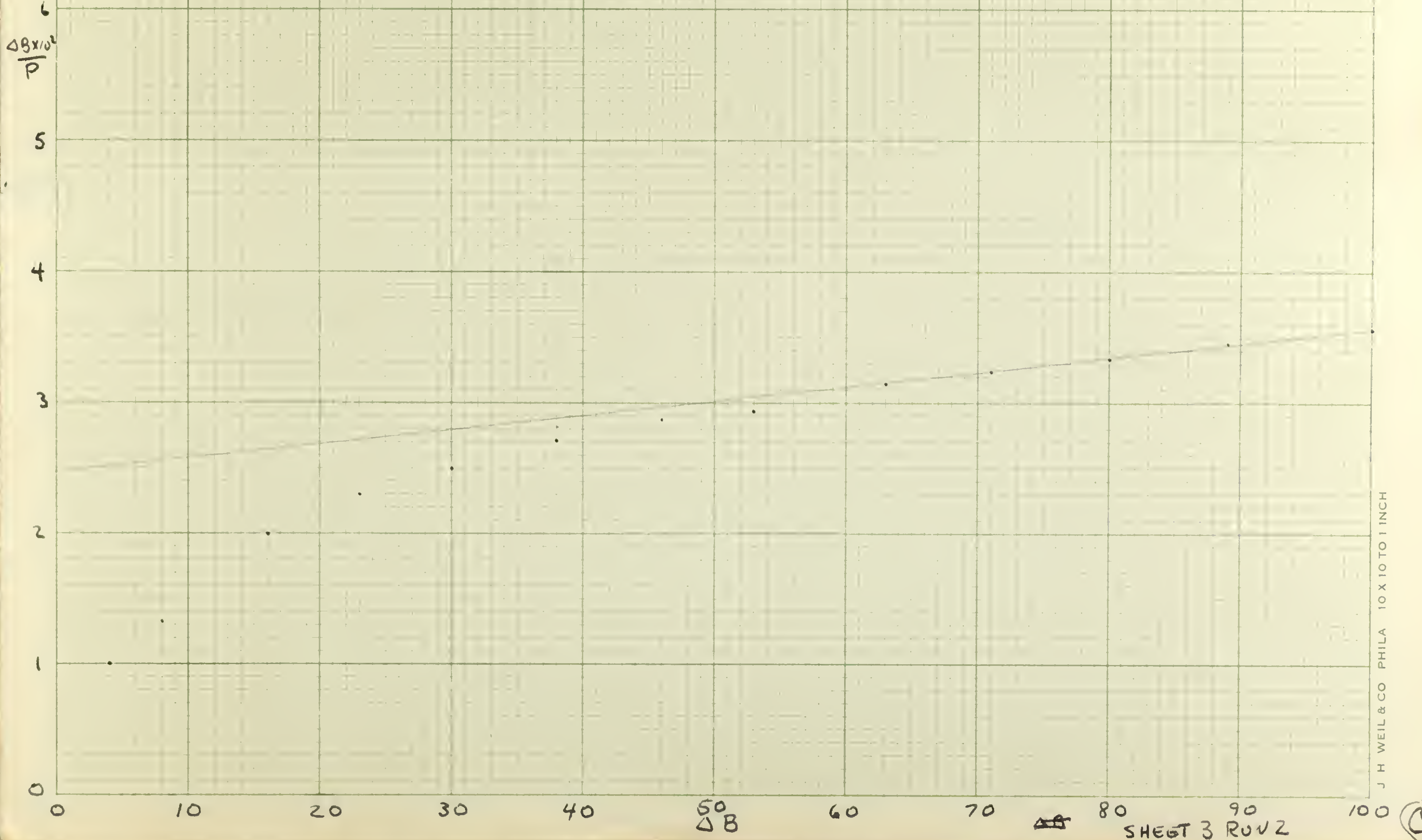
(C.)

PLOT $\frac{\Delta B \times 10^2}{P}$ VS ΔB

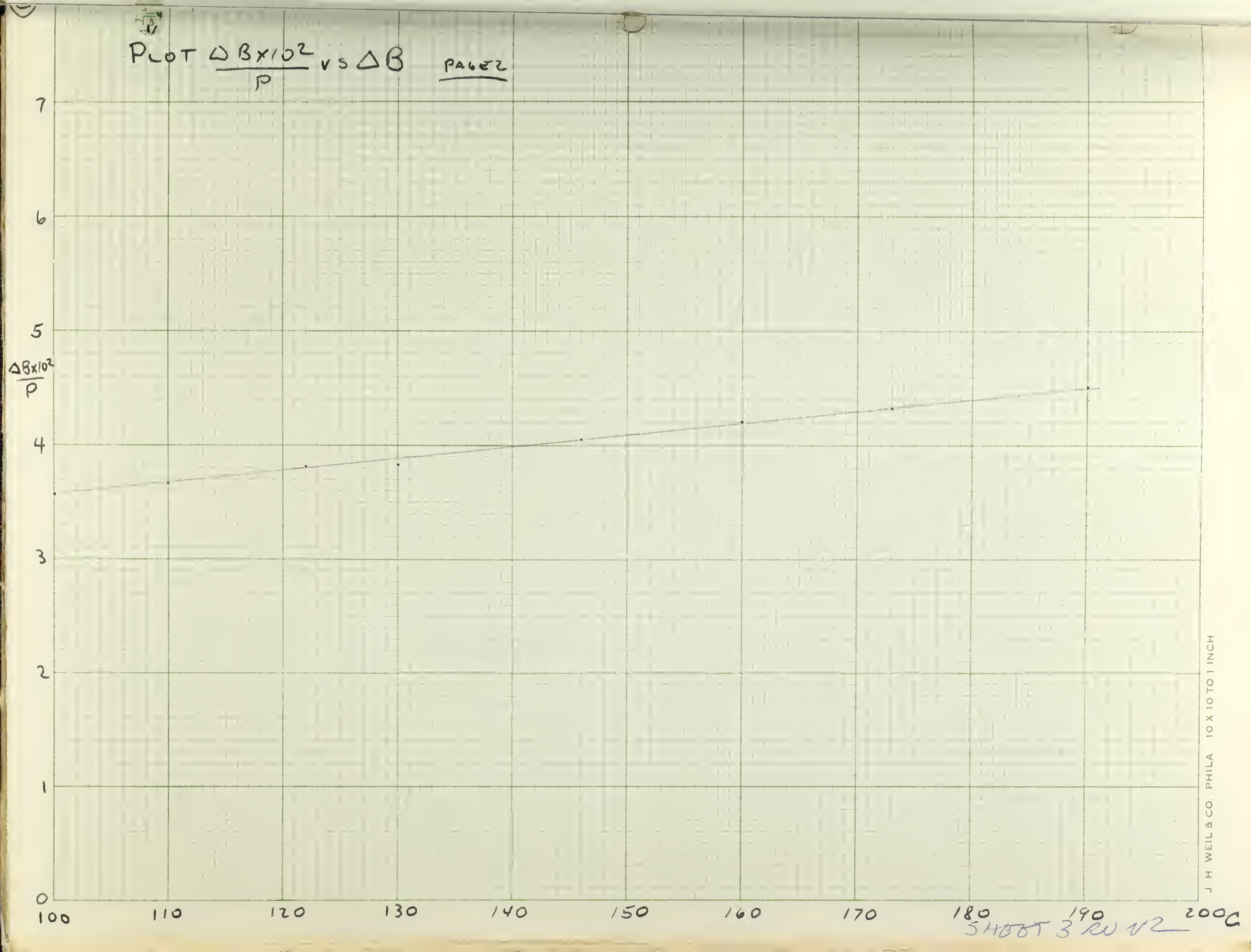
IN ORDER TO DETERMINE P_{cr} BY SLOPE METHOD.

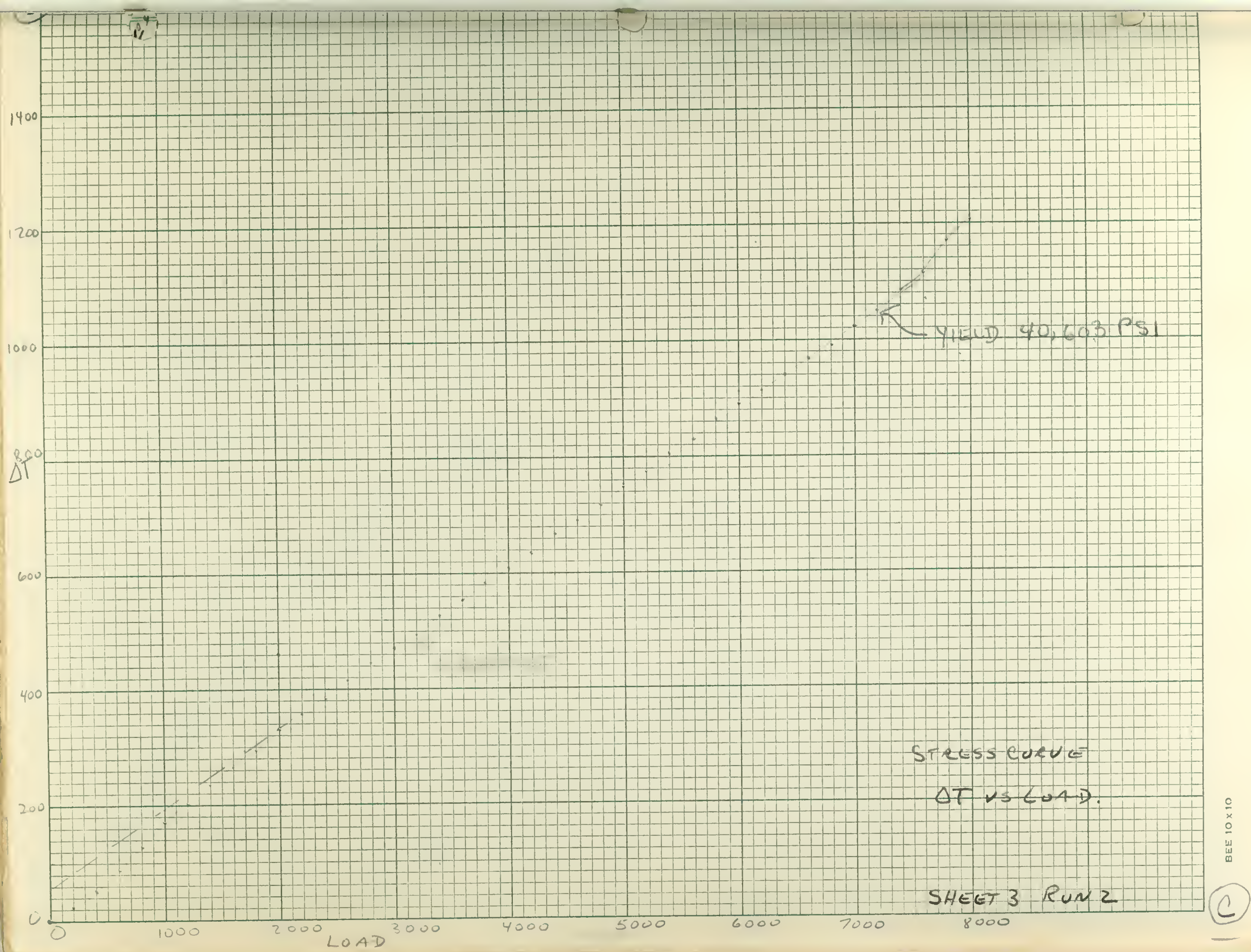
P_{cr} BY SLOPE = ~~909~~ 9313 LBS. σ_{cr} 18190 PSI

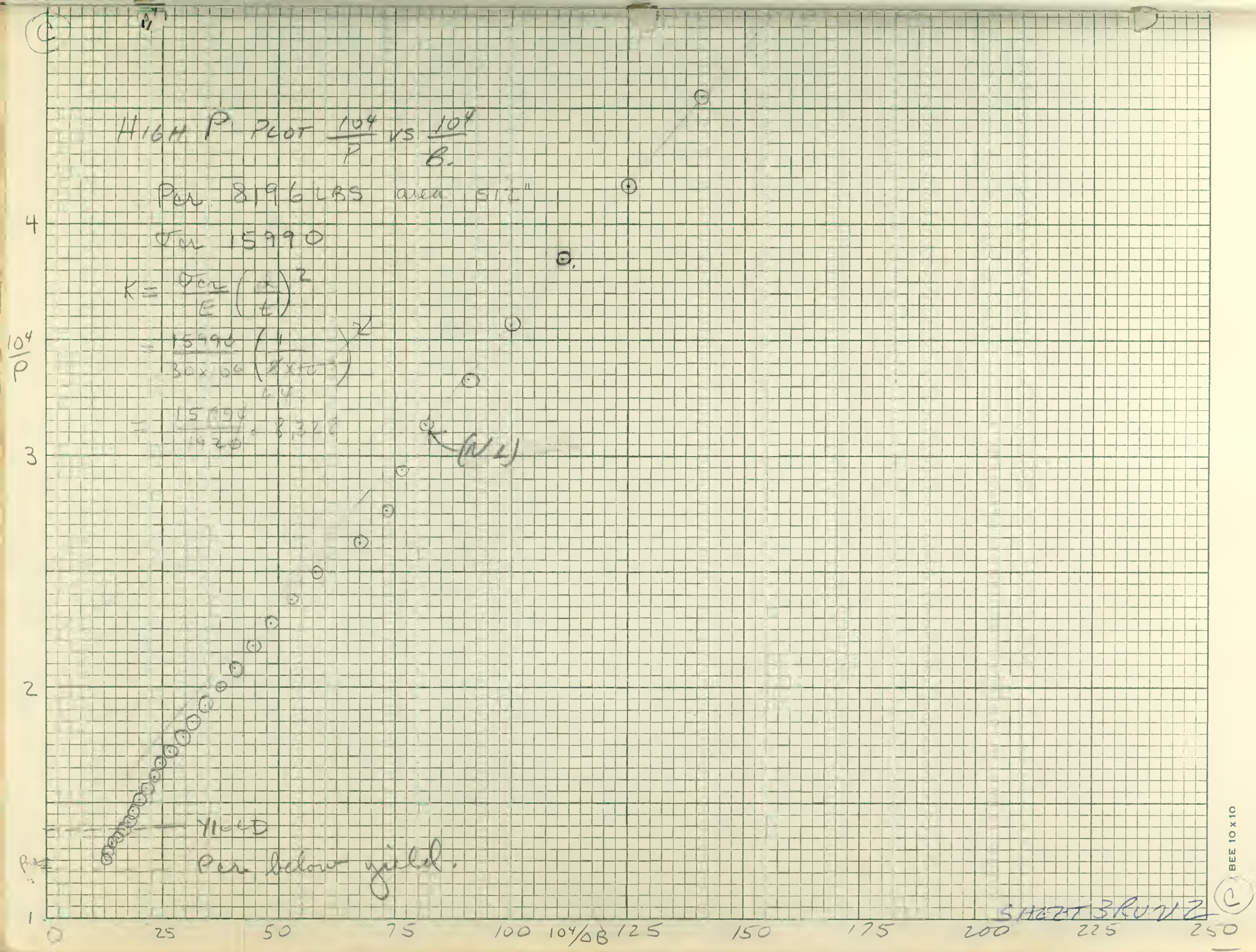
$$K = \frac{\sigma_{cr}}{E} \cdot \left(\frac{d}{t}\right)^2 = 9.473$$



SHEET 3 RUN 2


PLOT $\frac{\Delta B \times 10^2}{P}$ vs ΔB
PAGE 2
$\frac{\Delta B \times 10^2}{P}$
7
6
5
4
3
2
1
0
100
110
120
130
140
150
160
170
180
190
200
C
J H WEIL & CO PHILA 10 X 10 TO 1 INCH
SHEET 3 RN V2


YIELD 40,603 PSI
STRESS CURVE
ΔT vs LOAD.
SHEET 3 RUN 2
ΔT
0
200
400
600
800
1000
1200
1400
LOAD
0
1000
2000
3000
4000
5000
6000
7000
8000
BEE 10 x 10
C



High P Plot $\frac{10^4}{P}$ vs $\frac{10^4}{B}$.
Pcr 8196 LBS area .512"
σ_{cr} 15990
$K = \frac{\sigma_{cr}}{E}\left(\frac{a}{t}\right)^2$
$= \frac{15990}{30 \times 10^6}\left(\frac{1}{.2 \times .0?}\right)^2$
$= \frac{15990}{1420} = 8.328$
(NL)
Yield
Pcr below yield.
4
3
2
1
$\frac{10^4}{P}$
0
25
50
75
100
$10^4/\Delta B$
125
150
175
200
225
250
SHEET 3 RUN 2
BEE 10 x 10

P	$10^4/P$	B	$B-B_0$	$10^4/\Delta B$	$\Delta B\,10^4/P$	T	ΔT	STRESS PSI.
0		579	0			1130	0.	
100	100	575	-4		—	1165	35	
200	50	576	-3		—	1200	70	
300	33.3	575	-4		—	1229	99	
400	25.0	575	-4		—	1260	130	
600	16.7	573	-6		—	1316	186	
800	12.5	574	-5		—	1373	243	
1000	10.0	574	-5		—	1435	305	
1200	8.33	575	-4		—	1492	362	
1400	7.14	576	-3		—	1548	418	
1500	6.67	578	-1		—	1605	465	
1600	6.24	579	0	—	—			
1700	5.88	580	+1	10^4	5.88	1638	508	
1800	5.56	581	+2	5000	11.1	1662	532	
1900	5.26	583	+4	2500	21.0	1690	560	
2000	5.00	585	+6	1660	30.0	1719	589	
2100	4.76	589	+10	1000	47.6	1742	612	
2200	4.54	590	+11	909	50.0	1776	646	
2300	4.35	592	+13	769	56.5	1801	661	
2400	4.16	598	+19	526	79.2	1830	700	
2500	4.00	600	21	476	84.0	1856	726	
2600	3.84	604	25	400	96.2	1885	755	
2700	3.70	610	31	323	114.8	1912	782	
2800	3.57	618	39	256	139.2	1942	812	
2900	3.45	628	49	204	169.0	1968	838	
3000	3.33	640	61	164	2033	2000	870	

P	$10^4/P$	B	$B-B_0$	$10^4/\Delta B$	$\Delta B\,10^4/P$	T	ΔT	STRESS PSI
3200	3.13	682	103	97.1	321.9	2049	919	
3400	2.94	789	210	47.6	617.6	2106	976	
3600	2.78	938	359	27.8	997.2	2163	1033	
3800	2.63	1134	555	18.0	1461.	2229	1099	
4000	2.50	1311	732	13.7	1830	2292	1162	

SHEET 4 RUN 1.

I.

I. Plot of $\frac{10^4}{P}$ vs $\frac{10^4}{B}$

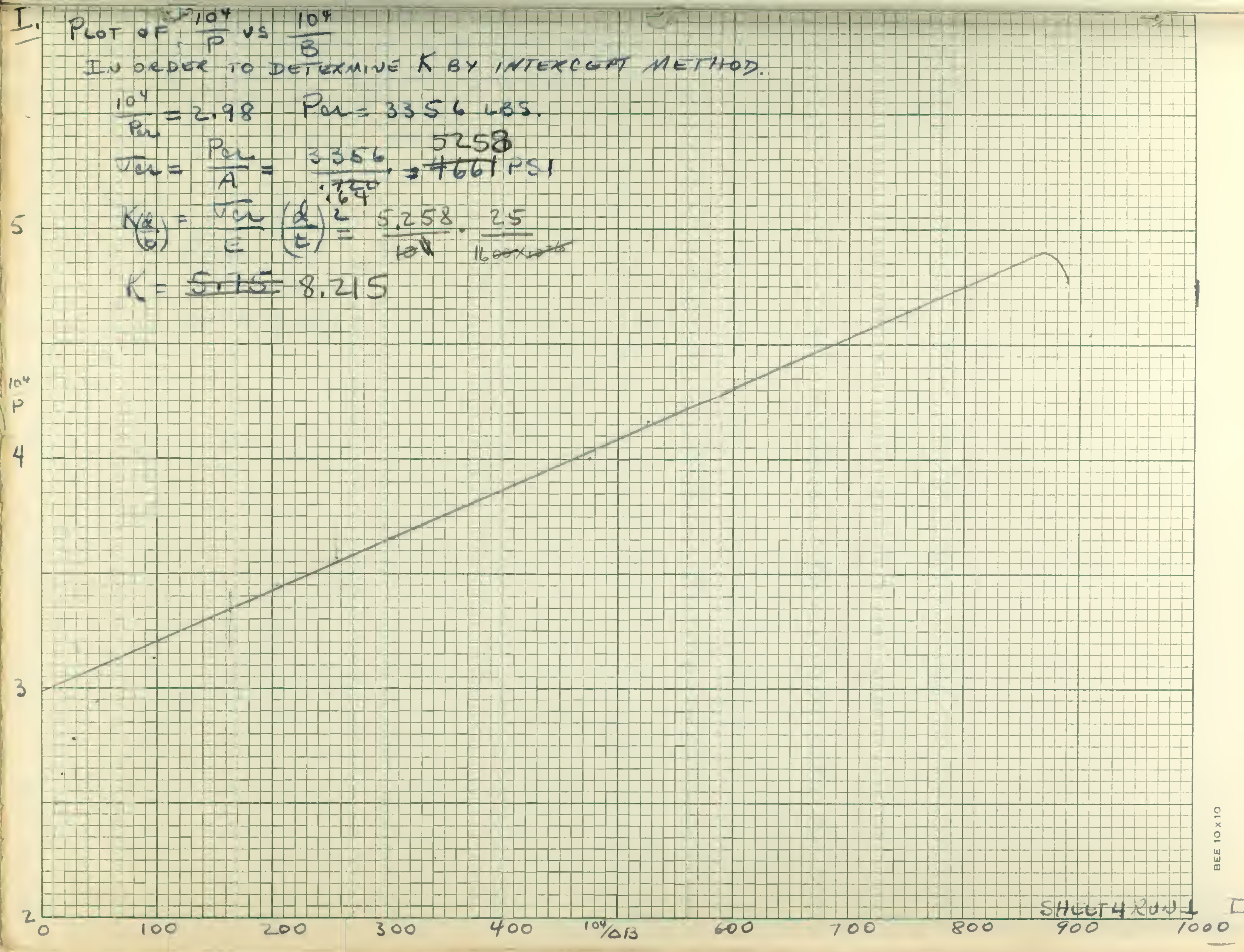
In order to determine K by intercept method.

$\frac{10^4}{P_{cr}} = 2.98 \qquad P_{cr} = 3356$ LBS.

$\sigma_{cr} = \frac{P_{cr}}{A} = \frac{3356}{\cancel{.720}\ .64} = \cancel{4661}\ 5258$ PSI

$K\left(\frac{a}{b}\right) = \frac{\sigma_{cr}}{E}\left(\frac{d}{t}\right)^2 = \frac{5.258}{10^6} \cdot \frac{25}{1600 \times \cancel{10^{-6}}}$

$K = \cancel{5.15}\ 8.215$



I.

Plot of $\frac{\Delta B}{P} \times 10^4$ vs ΔB

In order to determine K by slope method.

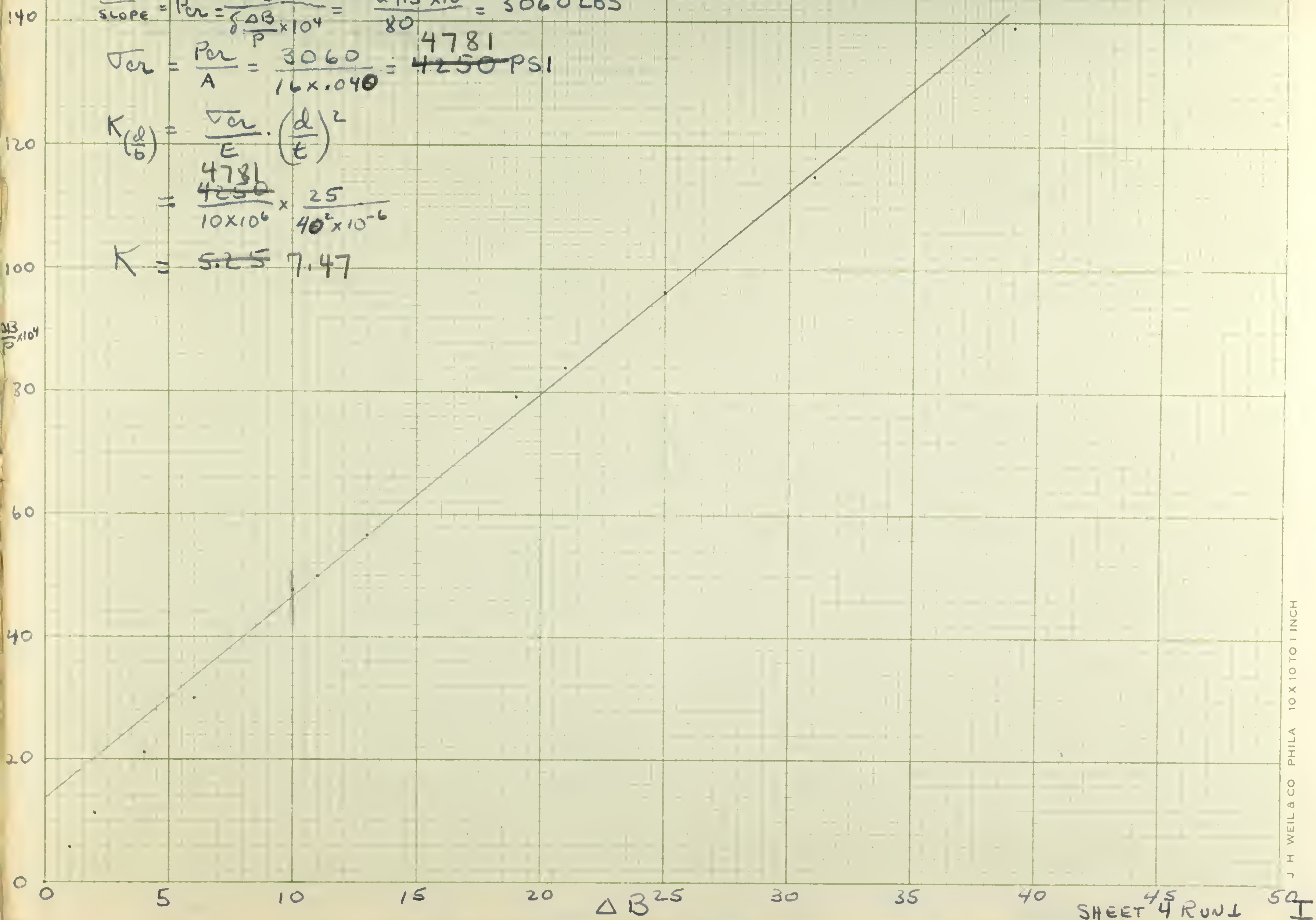
$$\frac{1}{\text{slope}} = P_{cr} = \frac{\delta \Delta B \times 10^4}{\delta \frac{\Delta B}{P} \times 10^4} = \frac{24.5 \times 10^4}{80} = 3060 \text{ LBS}$$

$$\sigma_{cr} = \frac{P_{cr}}{A} = \frac{3060}{16 \times .040} = \cancel{4250}\ 4781 \text{ PSI}$$

$$K_{\left(\frac{d}{b}\right)} = \frac{\sigma_{cr}}{E} \cdot \left(\frac{d}{t}\right)^2$$

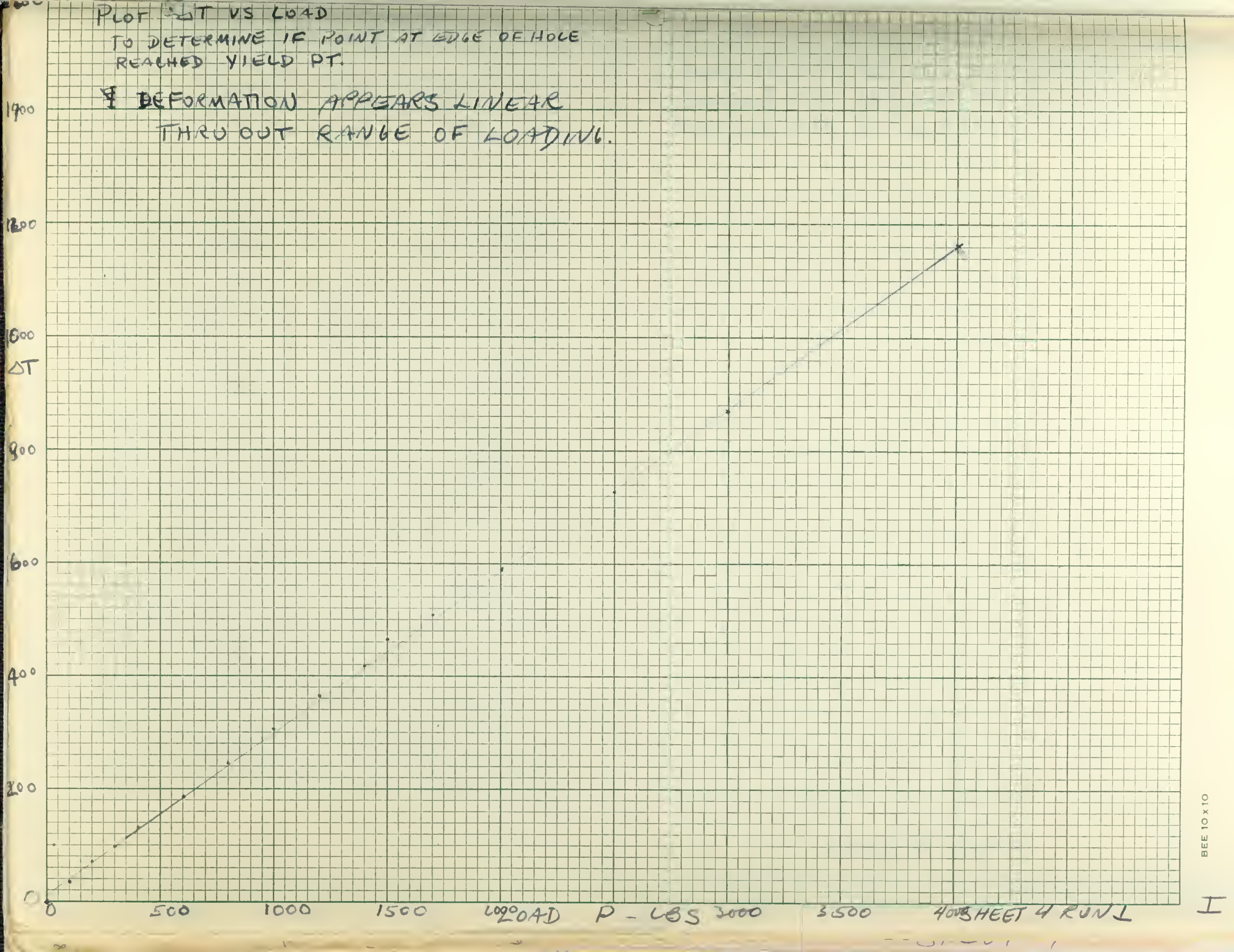
$$= \frac{\cancel{4250}\ 4781}{10 \times 10^6} \times \frac{25}{40^2 \times 10^{-6}}$$

$$K = \cancel{5.25}\ 7.47$$



SHEET 4 RUN 1

I


PLOT ΔT VS LOAD
TO DETERMINE IF POINT AT EDGE OF HOLE
REACHED YIELD PT.
DEFORMATION APPEARS LINEAR
THRU OUT RANGE OF LOADING.
ΔT
1400
1200
1000
800
600
400
200
0
500
1000
1500
2000
3000
3500
4000
LOAD P - LBS
SHEET 4 RUN I
I
BEE 10 x 10

P	1/P	B	B-Bo	$10^4/\Delta B$	$\frac{\Delta B \times 10^4}{P}$	T	ΔT	STRESS PSI
0	—	635	0			891	0	
100	100	633	-2			942	51	
200	50	631	-4			982	91	
300	33.3	632	-3			1022	131	
400	25.0	633	-2			1049	158	
600	16.7	633	-2			1123	232	
800	12.5	633	-2			1199	308	
1000	10.0	636	1	10^4	10.0	1269	378	
1200	8.33	637	2	5000	16.7	1334	443	
1400	7.14	638	3	3333	21.4	1405	514	
1500	6.67	638	3	3333	20.0	1439	548	
1600	6.24	640	5	2000	31.3	1473	582	
1700	5.88	642	7	1429	41.2	1508	617	
1800	5.56	645	10	1000	55.6	1544	653	
1900	5.26	646	11	909	57.9	1573	682	
2000	5.00	648	13	769	65.0	1610	719	
2100	4.76	650	15	661	71.4	1645	754	
2200	4.54	653	18	556	81.8	1678	787	
2300	4.35	657	22	455	95.7	1712	821	
2400	4.16	662	27	370	112.5	1742	851	
2600	3.84	674	39	256	150.0	1810	919	
2800	3.57	689	54	185	193.	1871	980	
3000	3.33	721	86	116	287.	1938	1047	
3200	3.13	789	154	64.9	481.3	2000	1109	
3400	2.94	915	280	35.7	823.5	2064	1173	
3600	2.78	1100	465	21.5	305.5	2132	1241	
3800	2.63	1300	665	15.0	342.1	2202	1361	
4000	2.50	1472	837	11.9	368.0	2265	1374	

SHEET 4 RUN 2

J

Plot of $\frac{10^4}{\Delta P}$ vs $\frac{10^4}{\Delta B}$

To determine K by intercept method.

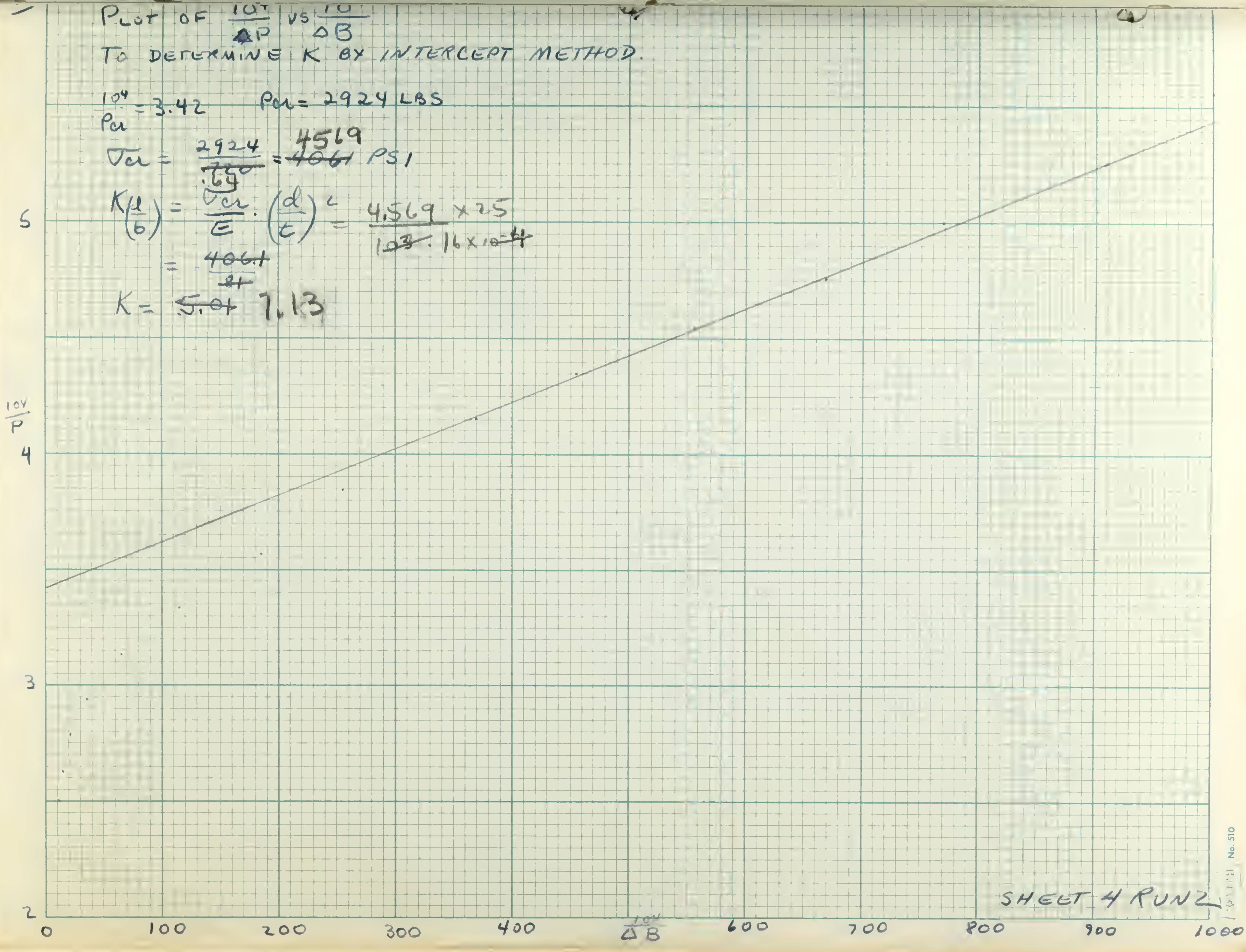
$\frac{10^4}{P_{cr}} = 3.42$ $\quad P_{cr} = 2924$ LBS

$\sigma_{cr} = \frac{2924}{\cancel{.720}\ .64} = \cancel{4061}\ 4569$ PSI

$K\left(\frac{\mu}{b}\right) = \frac{\sigma_{cr}}{E} \cdot \left(\frac{d}{t}\right)^2 = \frac{4.569 \times 25}{\cancel{1.03} \cdot 16 \times 10^{-4}}$

$= \frac{\cancel{406.1}}{\cancel{81}}$

$K = \cancel{5.01}\ 7.13$



PLOT OF $\frac{\Delta B \times 10^4}{P}$ VS ΔB

TO DETERMINE K BY THE SLOPE METHOD.

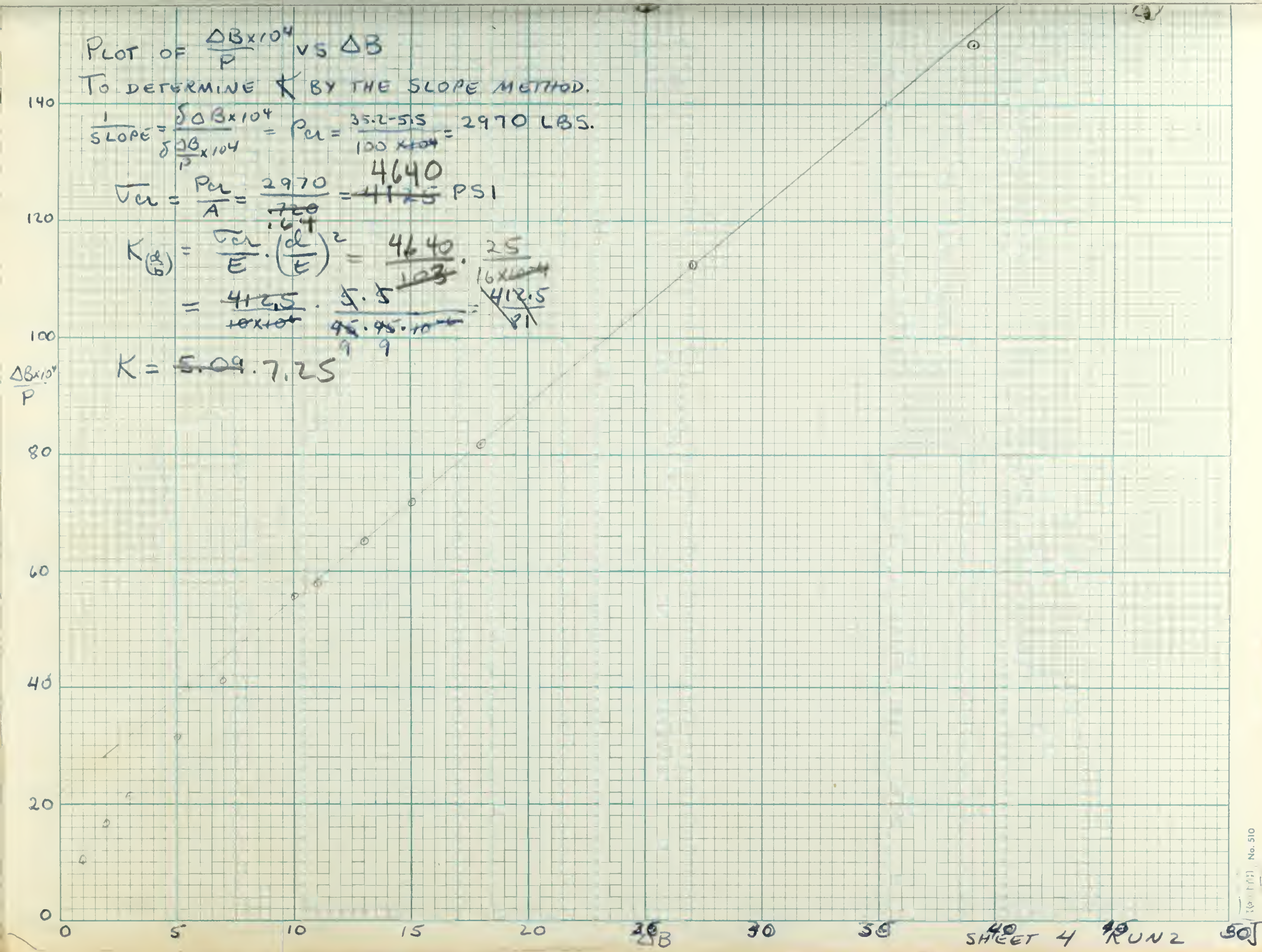
$$\frac{1}{\text{SLOPE}} = \frac{\delta \Delta B \times 10^4}{\delta \frac{\Delta B}{P} \times 10^4} = P_{cr} = \frac{35.2-5.5}{100 \cancel{\times 10^4}} = 2970 \text{ LBS.}$$

$$\sigma_{cr} = \frac{P_{cr}}{A} = \frac{2970}{\cancel{.720}\ .64} = \cancel{4125}\ 4640 \text{ PSI}$$

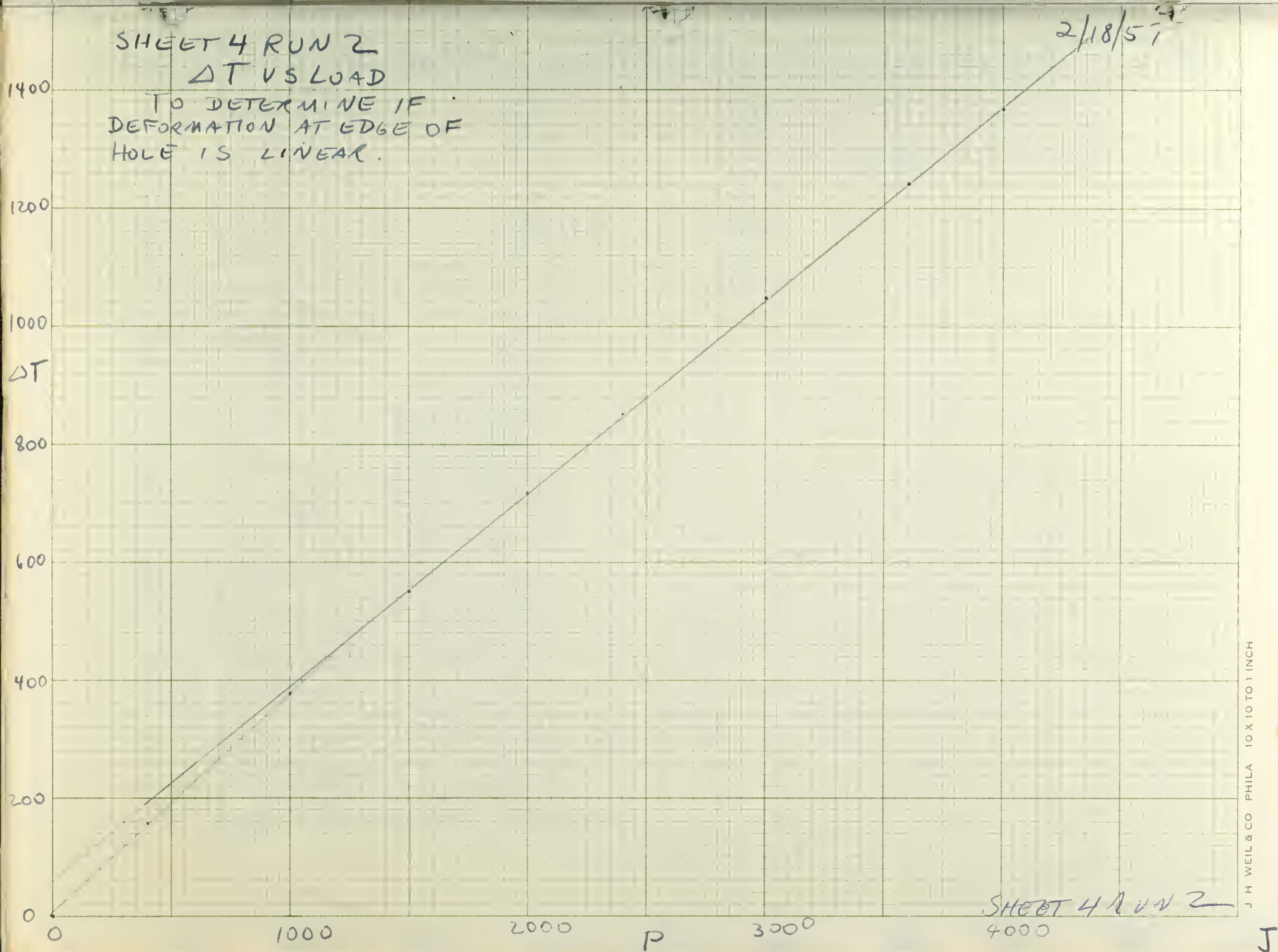
$$K_{\left(\frac{a}{b}\right)} = \frac{\sigma_{cr}}{E} \cdot \left(\frac{a}{t}\right)^2 = \frac{4640}{\cancel{10^3}} \cdot \frac{25}{16 \times \cancel{10^{-4}}}$$

$$= \cancel{\frac{412.5}{10 \times 10^4}} \cdot \frac{5.5}{\cancel{45} \cdot \cancel{45} \cdot \cancel{10^{-6}}\ 9 \cdot 9} = \cancel{\frac{412.5}{81}}$$

$$K = \cancel{5.09}\ 7.25$$



SHEET 4 RUN 2



SHEET 4 RUN 2
ΔT VS LOAD
TO DETERMINE IF DEFORMATION AT EDGE OF HOLE IS LINEAR.
2/18/57
ΔT
1400
1200
1000
800
600
400
200
0
P
1000
2000
3000
4000
SHEET 4 RUN 2
J H WEIL & CO PHILA 10 X 10 TO 1 INCH
J.

K SHEET 4 RUN 3 x.040 ALUM WITH HOLE

LOAD P	$10^4/P$	B	ΔB	$10^4/\Delta B$	$\frac{\Delta B}{P} \times 10^4$	T	ΔT	STRESS PSI		P	$10^4/P$	B	ΔB	$10^4/\Delta B$	$\frac{\Delta B}{P} \times 10^4$	T	ΔT	STRESS PSI.
0		649				878	0			3400	2.94	930	281	35.5	8245	2054		
100	100	645	-4			925				3600	2.78	1118	469	21.3	1303	2124		
200	50	644	-5			965				3800	2.63	1300	651	15.4	1713	2195		
300	33.3	645	-4			1005				4000	2.50	1480	831	12.0	2077	2260		
400	25.0	642	-7			1054				4200								
500	20.0	642	-7			1090	212			4600								
600	16.7	642	-7			1127				4900								
800	12.5	643	-6			1198				5000								
1000	10	644	-5			1265	387											
1200	8.33	646	-3			1331												
1400	7.14	649	0			1398												
1500	6.67	650	+1	10^4	6.67	1430												
1600	6.24	651	+2	5000	12.25	1463												
1700	5.88	652	+3	3333	17.65	1499												
1800	5.56	655	+6	1660	33.33	1532												
1900	5.26	656	+7	1428	36.84	1554												
2000	5.00	660	11	909	55.00	1599												
2100	4.76	662	13	769	61.90	1631												
2200	4.54	665	16	625	72.73	1662												
2300	4.35	669	20	500	86.96	1699												
2400	4.16	672	23	435	95.83	1730												
2500	4.00	679	30	333	120.0	1761												
2600	3.84	683	34	294	130.8	1793												
2700	3.70	692	43	233	159.3	1831												
2800	3.57	700	51	196	182.1	1862												
2900	3.44	712	63	159	217.2	1900												
3000	3.33	732	83	120	276.7	1929												
3200	3.13	800	151	66.2	471.9	1995												

SHEET 4 RUN 3

Plot $\frac{\Delta B}{P} \times 10^4$ vs ΔB.

Calculation of K by Slope Method.

$$P_{cr} = \left(\frac{\Delta B}{\frac{\Delta B}{P}\times 10^4}\right)\left(10^{+4}\right) = \left(\frac{36.8 - 5.6}{100}\right)\left(10^{+4}\right) = 3120 \text{ LBS}$$

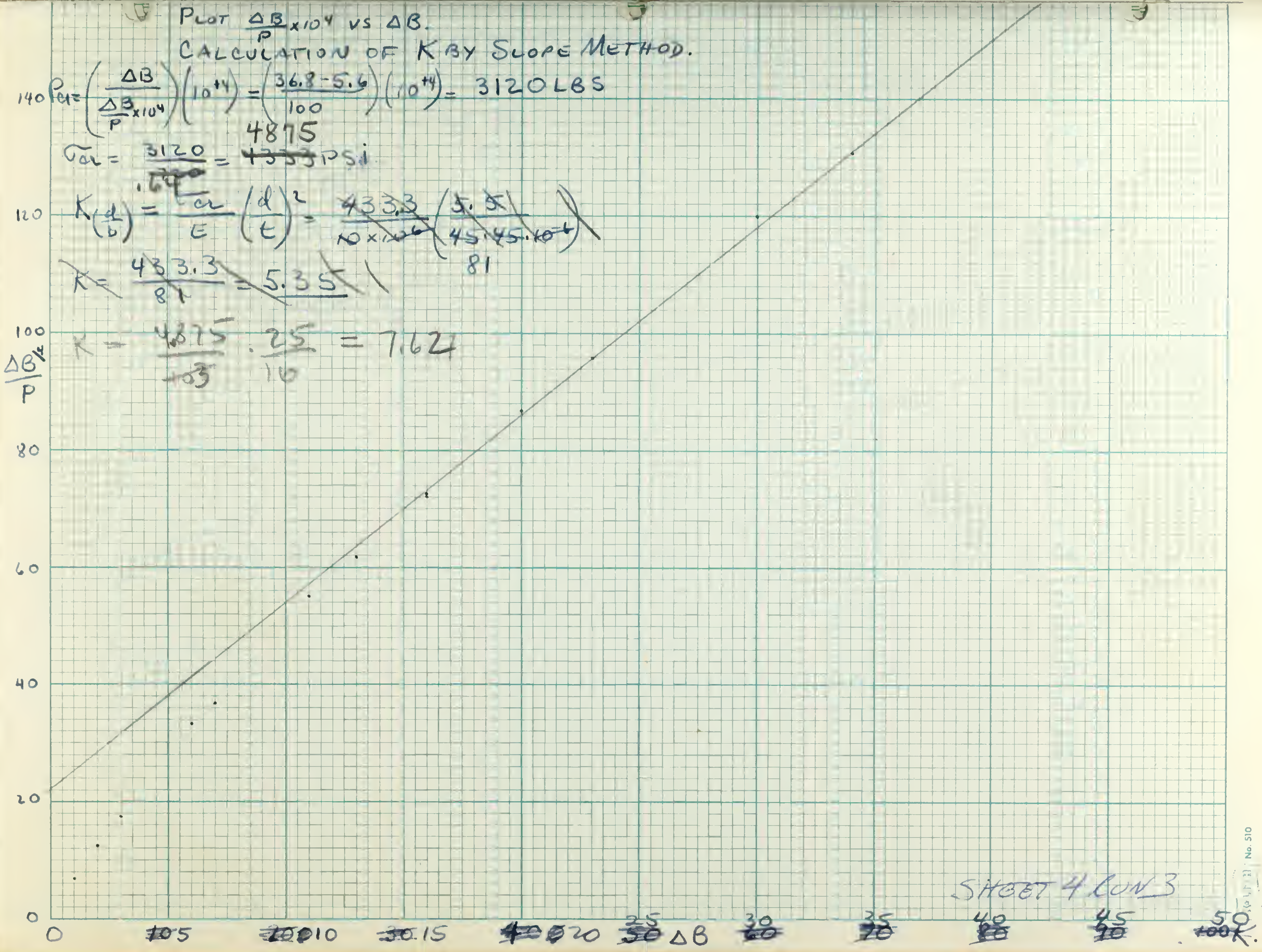
$$\sigma_{cr} = \frac{3120}{.64} = \cancel{1333}\ 4875 \text{ PSI}$$

$$K_{\left(\frac{d}{b}\right)} = \frac{\sigma_{cr}}{E}\left(\frac{d}{t}\right)^2 = \cancel{\frac{433.3}{10\times 10^6}\left(\frac{5.5}{45\cdot 45\cdot 10^{-6}}\right)}$$

81

$$\cancel{K = \frac{433.3}{81} = 5.35}$$

$$K = \frac{4875}{10^3} \cdot \frac{25}{16} = 7.62$$



Sheet 4 Con 3

No. 510

Plot $\frac{10^4}{P}$ vs $\frac{10^4}{B}$.

IN ORDER TO DETERMINE K BY INTERCEPT METHOD.

$\frac{10^4}{P_{cr}} = 3.41$

$P_{cr} = 2932$ LBS

$\sigma_{cr} = \frac{2932}{.64\ \cancel{.720}} = \cancel{4072}\ 4581$ PSI.

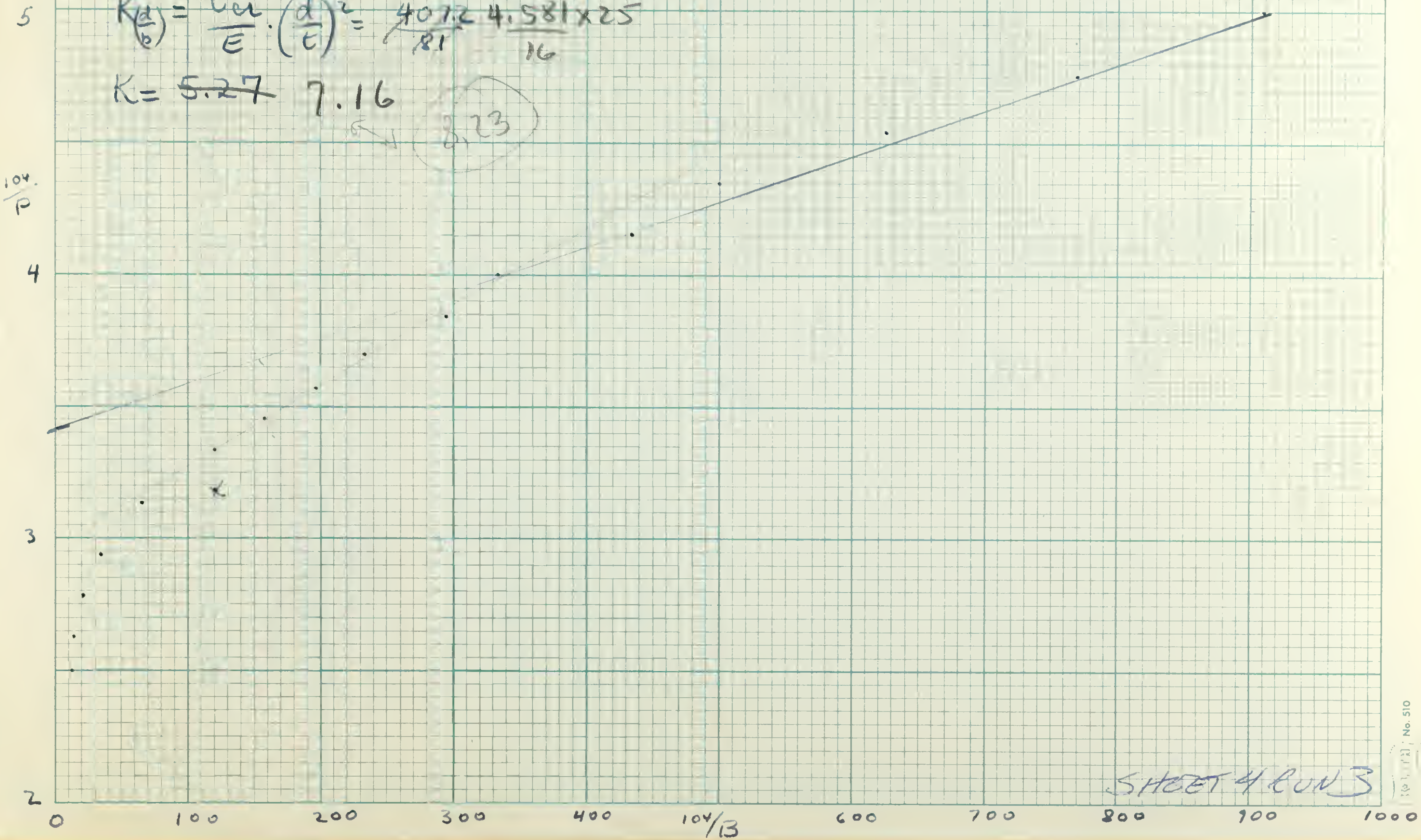
3370

527

$K\left(\frac{d}{b}\right) = \frac{\sigma_{cr}}{E}\cdot\left(\frac{d}{t}\right)^2 = \cancel{\frac{4072}{81}}\ \frac{4.581 \times 25}{16}$

$K = \cancel{5.27}\ 7.16$

8.23



SHEET 4 RUN 3

No. 510

SHEET 5 RUN 1 2/22/57

LOAD P	$10^4/P$	B	ΔB	$10^4/ΔB$	$\frac{ΔB}{P} \times 10^4$	T	ΔT	STRESS	TIME	P	$10^4/B$	B	ΔB	$10^4/ΔB$	$\frac{ΔB}{P} \times 10^4$	T	ΔT	STRESS
0		791				~~1520~~			START 1000	3100		890	99		319			
100		792	1	~~100~~	100				813 1023	3200		892	101		316			
200		798	7	50	350	1500				3300		900	109		330			
300		800	10		~~333~~ 300					3400		904	113		332			
400		801	10		250					3500		908	117		334			
500		805	14		280				818 1022	3600		912	121		336			
600		803	12		200					3800		928	137		361			
800		815	24		300					4000		940	149		373			
1000		820	29		290													
1200		825	34		283													
1400		830	39		279													
1500		832	41		273													
1600		836	45		281													
1700		839	48		282													
1800		840	49		272													
1900		843	52		274				1010									
2000		849	58		290				852 1020									
2100		850	59		280				~~849~~ 1027									
2200		852	61		277				858 1028									
2300		856	65		283													
2400		860	69		283													
2500		864	73		292													
2600		870	79		304													
2700		871	80		296													
2800		875	84		300													
2900		880	89		306													
3000		883	92		307													

1020

SHEET 5 RUN ~~E~~ E

SHEET 5 RUN 1   24S-T3   16 X 36 X .040 WITH 4" HOLE

2/22

$\frac{\Delta B}{P}10^{4}$ vs ΔB

$$P_{cr} = \frac{\delta \Delta B}{\delta \frac{\Delta B}{P} \times 10^{4}} = \frac{60}{313 - 265} \times 10^{4} = \frac{600{,}000}{48}$$

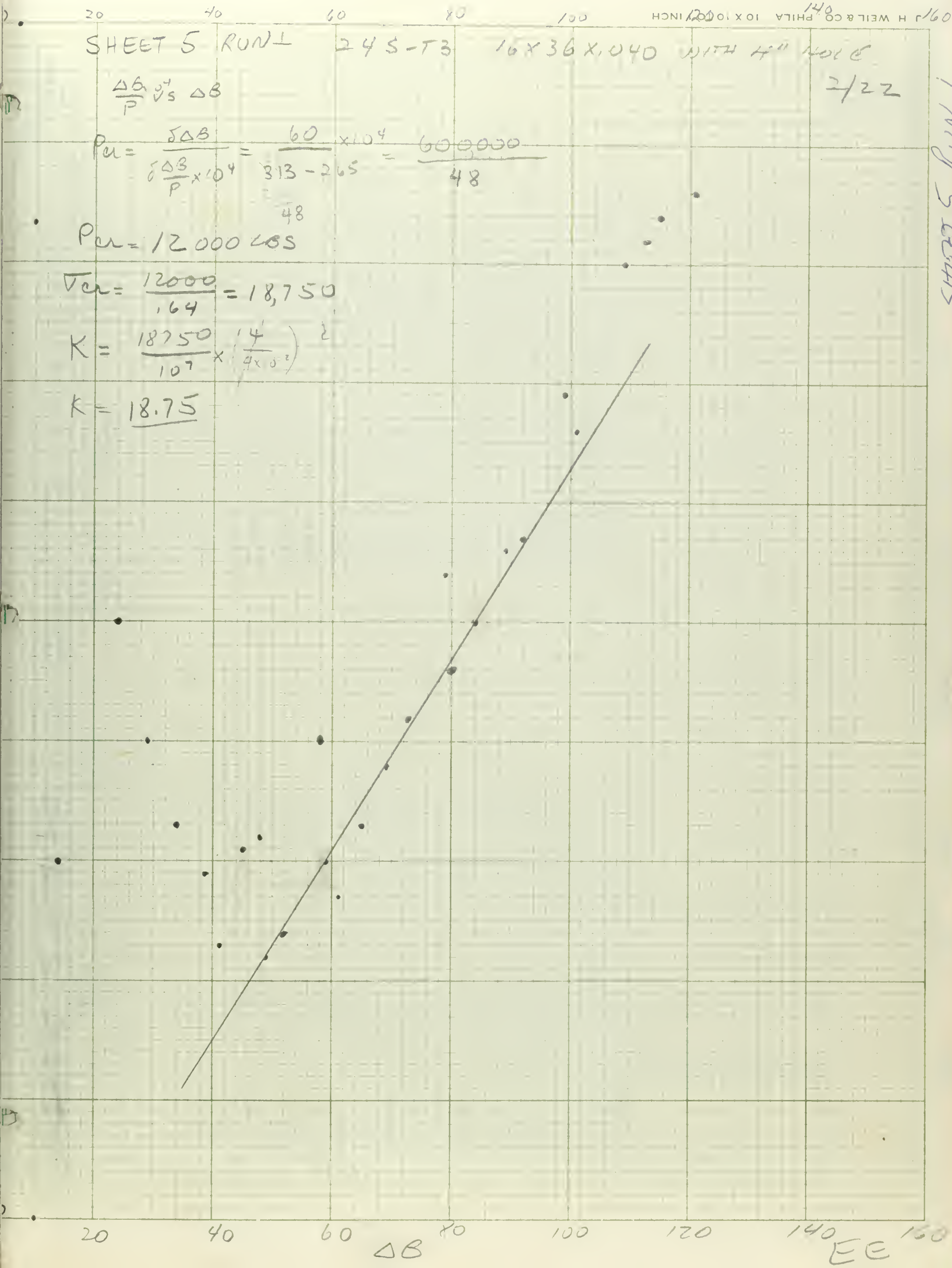
48

$P_{cr} = 12000$ LBS

$$\sigma_{cr} = \frac{12000}{.64} = 18{,}750$$

$$K = \frac{18750}{10^{7}} \times \left(\frac{14}{4 \times 0^{2}}\right)^{2}$$

$K = \underline{18.75}$



SHEET 5 RUN 1

EE

SHEET 5 RUN 3 2/20/57

LOAD P	$10^4/P$	B	ΔB	$10^4/\Delta B$	$\Delta B \times 10^4 / P$	T	ΔT	STRESS PSI.	TIME	LOAD P	$10^4/P$	B	ΔB	$10^4/\Delta B$	$\Delta B \times 10^4 / P$	T	ΔT	STRESS PSI.
0		847			—	1330			START 1424	2100	4.76	892	45	222	214	2012		
100	100	847	0	—	—				FINISH 1444	2200	4.54	899	52	192	236			
200	50	849	2	5000	100	1402			850-1382	2300	4.35	900	53	189	230			
300	33.3	850	3	3333	100					2400	4.16	900	53	189	221			
400	25.0	851	4	2500	100					2500	4.00	905	58	172	232			
500	20.0	852	5	2000	100	1505				2600	4.84	909	62	161	238			
600	16.7	856	9	1111	150					2700	3.70	911	64	156	237			
700	14.3	859	12	833	171					2800	3.57	915	68	147	243	2238		
800	12.5	861	14	714	175					2900	3.44	920	73	136	252			
900	11.1	863	16	625	178					3000	3.33	923	76	132	253			
1000	10.0	867	20	500	200	1675				3100	3.23	928	81	123	261	2330		
1100	9.09	870	23	435	209					3200	3.13	930	83	120	259			
1200	8.33	870	23	435	191					3300	3.03	937	90	111	273			
1300	7.69	872	25	400	192					3400	2.94	940	93	108	274			
1400	7.14	873	26	385	186					3500	2.86	948	101	99.0	288			
1500	6.67	879	32	313	213	1830				3600	2.78	950	103	97.0	286			
1600	6.24	880	33	303	206					3700	2.70	958	111	90.1	300	2520		
1700	5.88	882	35	286	205					3800	2.63	962	115	87.0	303			
1800	6.56	885	38	263	211					3900	2.56	970	123	81.3	315			
1900	5.26	888	41	244	216					4000	2.50	978	131	76.3	328	2610		
2000	5.00	890	43	233	215													

DD

SHEET 5 RUN 3

Plot of $\frac{\Delta B}{P} \times 10^4$ vs ΔB

To determine K by slope method

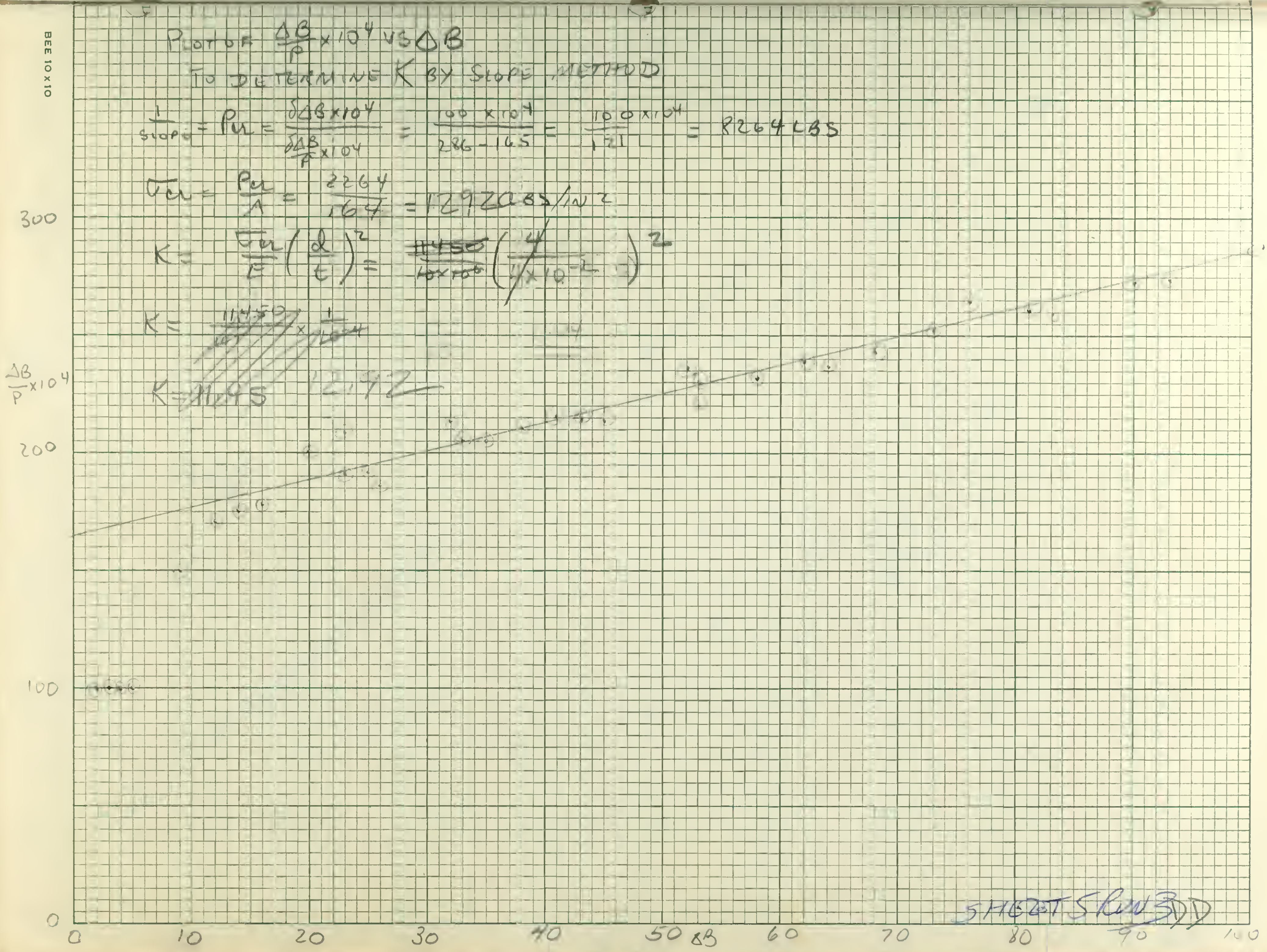
$$\frac{1}{\text{slope}} = P_{cr} = \frac{\delta \Delta B \times 10^4}{\delta \frac{\Delta B}{P} \times 10^4} = \frac{100 \times 10^4}{286 - 165} = \frac{100 \times 10^4}{121} = 8264 \text{ LBS}$$

$$\sigma_{cr} = \frac{P_{cr}}{A} = \frac{8264}{.64} = 12920 \text{ LBS/IN}^2$$

$$K = \frac{\sigma_{cr}}{E}\left(\frac{d}{t}\right)^2 = \frac{\cancel{11450}}{\cancel{10 \times 10^6}}\left(\frac{4}{\cancel{1 \times 10^{-2}}}\right)^2$$

$$K = \cancel{\frac{11450}{10^7}} \times \frac{1}{\cancel{10^{-4}}}$$

$K = \cancel{11.45}$ 12.42



BEE 10 x 10

SHEET 5 RUN 3 DD

DPLOT OF $\frac{10^4}{P}$ VS $\frac{10^4}{\Delta B}$

TO DETERMINE K BY INTERCEPT METHOD

$P_{cr} = \frac{10^4}{1.68} = 5950$ LBS

$\frac{10^4}{1.05} = 9540$

$2 \overline{)15490}$

P_{cr} 7745 LBS

$\sigma_{cr} = \frac{7745}{.720} = 10,750$ PSI

$K = \frac{\sigma_{cr}}{E}\left(\frac{d}{t}\right)^2 = \frac{10750}{\cancel{12 \times 10^6}} \times \frac{4 \times 4}{}$

K = ~~10.7~~

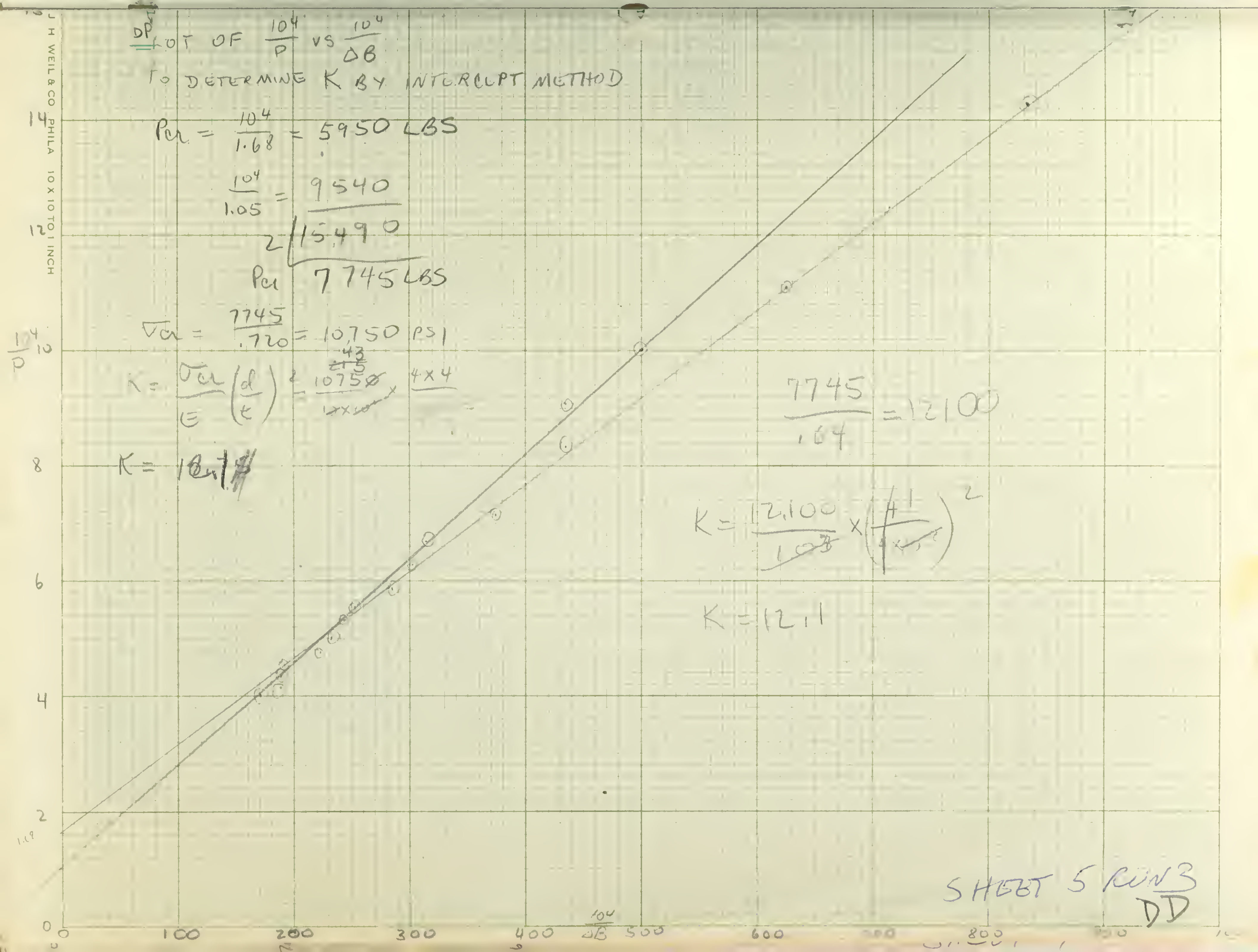
$\frac{7745}{.64} = 12100$

$K = \frac{12,100}{\cancel{10^3}} \times \left(\frac{4}{\cancel{4 \times 10^3}}\right)^2$

K = 12.1

SHEET 5 RUN 3

DD



LOAD P	$\frac{10^4}{P}$	B	ΔB	$\frac{\Delta B \times 10^4}{P}$	$\frac{10^4}{\Delta B}$	T	ΔT	STRESS		LOAD P	$10^4/P$	B	ΔB	$\frac{\Delta B \times 10^4}{P}$	$\frac{10^4}{B}$	T	ΔT	STRESS
0		750		—	—	110				1500								
100	100	810	60	6000	166.7	708	2			1550								
200	50.0	880	130	6500	76.9	692	18			1600								
300	33.3	958	208	6930	48.1	680	30											
400	25.0	1046	296	7400	33.8	666	44											
450	22.2	1080	330	7330	30.3	660	50											
500	20.00	1120	370	7400	27.0	652	58											
550	18.2	1160	410	7450	24.4	646	64											
600	16.7	1200	450	7500	22.2	638	72											
650	15.4	1241	491	7550	20.4	632	78											
700	14.3	1278	528	7540	18.9	624	86											
750	13.3	1320	570	7600	17.5	618	92											
800	12.50	1361	611	7640	16.4	610	100											
850	11.8	1404	654	7690	15.3	600	110											
900	11.1	1448	698	7760	14.3	592	118											
950	10.5	1482	732	7700	13.7	585	125											
1000	10	1525	775	7750	12.9	578	132											
1050	9.52	1568	818	7790	12.2	570	140											
1100	9.09	1608	858	7800	11.6	562												
1150	8.70	1652	902	7840	11.1	554												
1200	8.33	1680	930	7750	10.8	549												
1250	8.00	1728	978	7820	10.2	545												
1300	7.69	1770	1020	7850	9.8	538												
1350	7.41	1812	1062	7860	9.4	530												
1400																		
1450																		

RP-450

SHEET 6 RUN 1, L

To determine P_{cr} by slope method

$P_{cr} = \frac{1}{slope} = \left(\frac{\delta \Delta B}{\delta \frac{\Delta B}{P} \times 10^4}\right) \times 10^4 =$

$= \left(\frac{853 - 51}{1000}\right) \times 10^4 =$

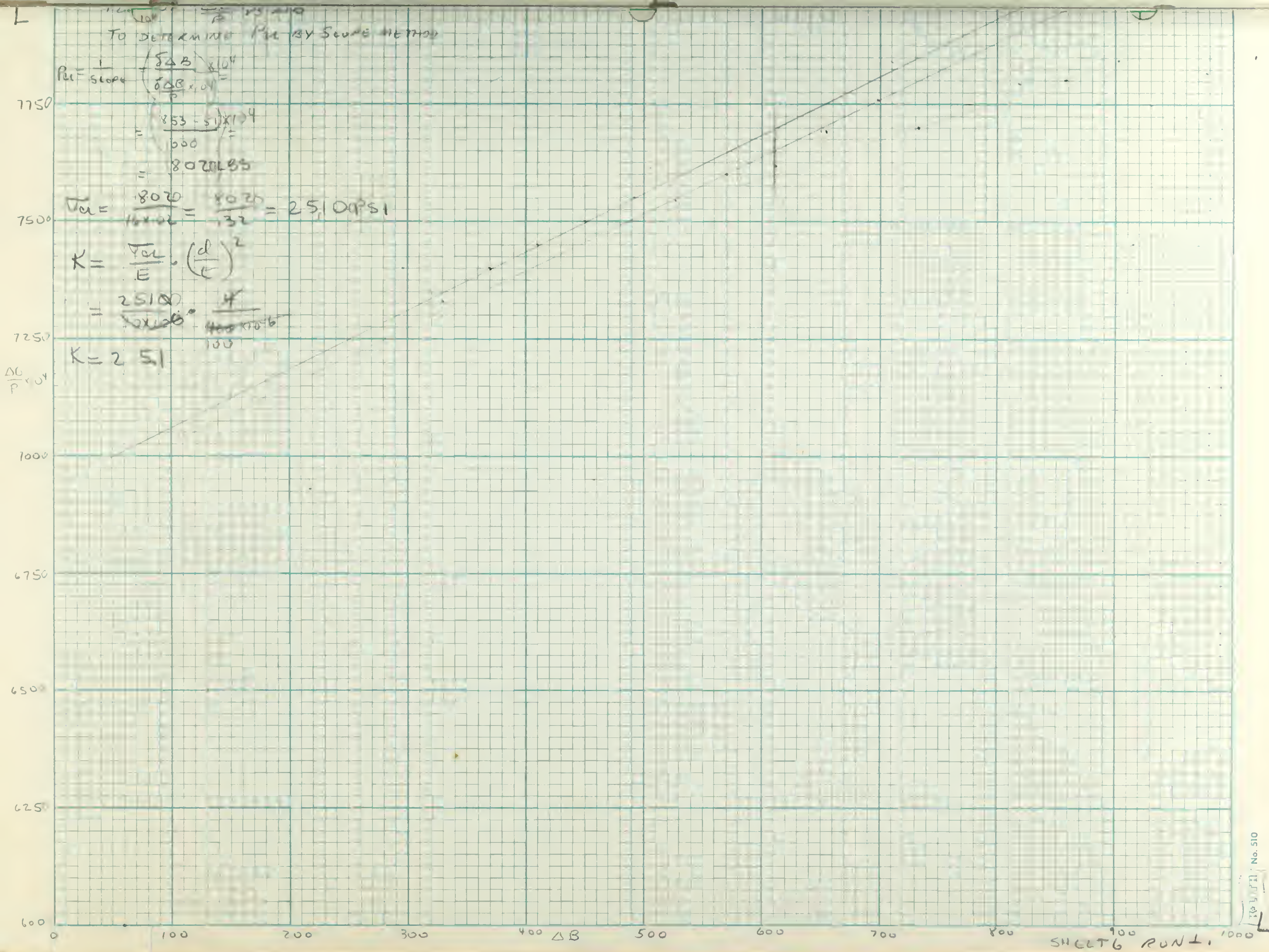
$= 8020$ LBS

$\sigma_{cr} = \frac{8020}{16 \times .02} = \frac{8020}{.32} = 25,100$ PSI

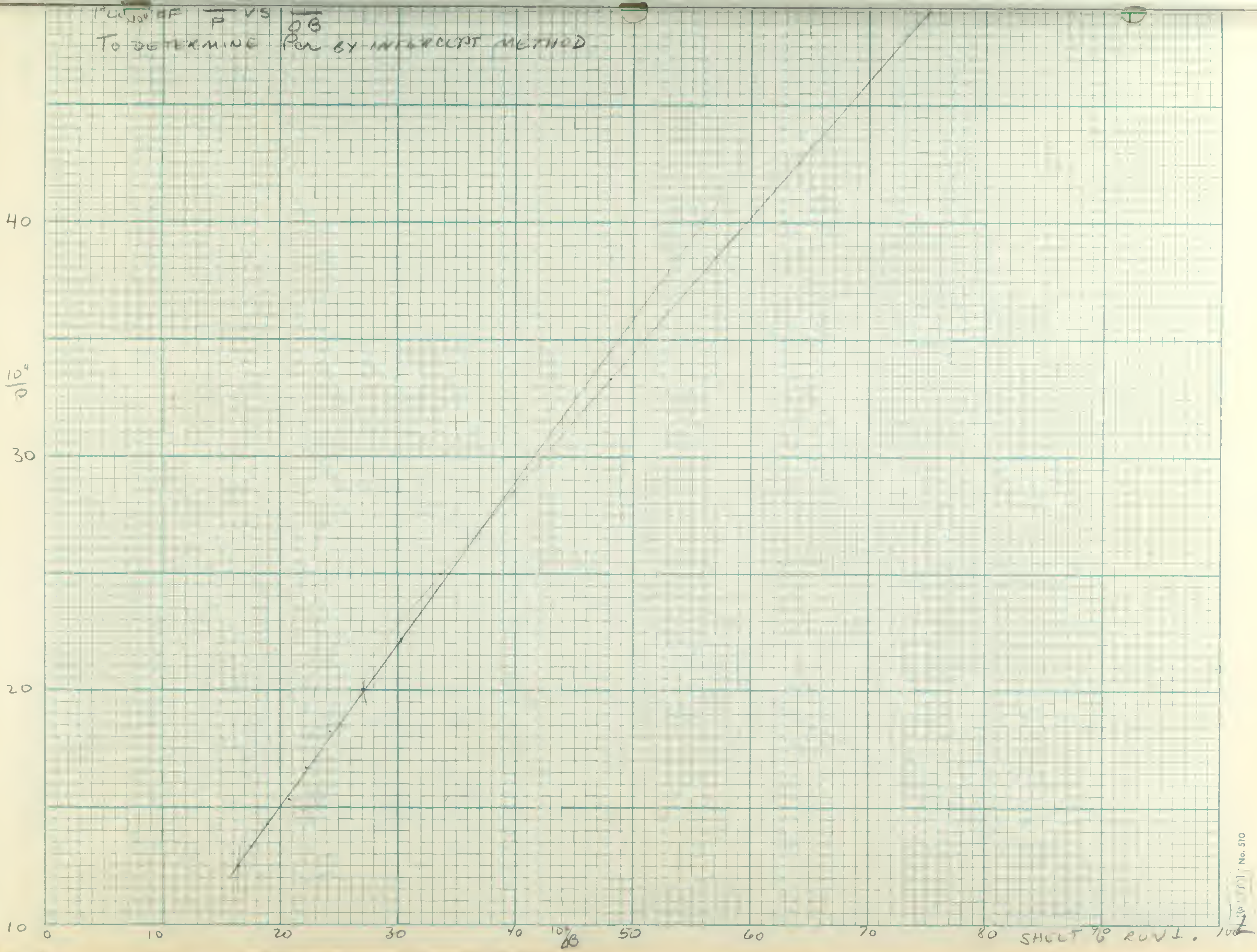
$K = \frac{\sigma_{cr}}{E} \cdot \left(\frac{d}{t}\right)^2$

$= \frac{25100}{10 \times 10^6} \cdot \frac{4}{\cancel{400 \times 10^{-6}}\ 100}$

$K = 2.51$

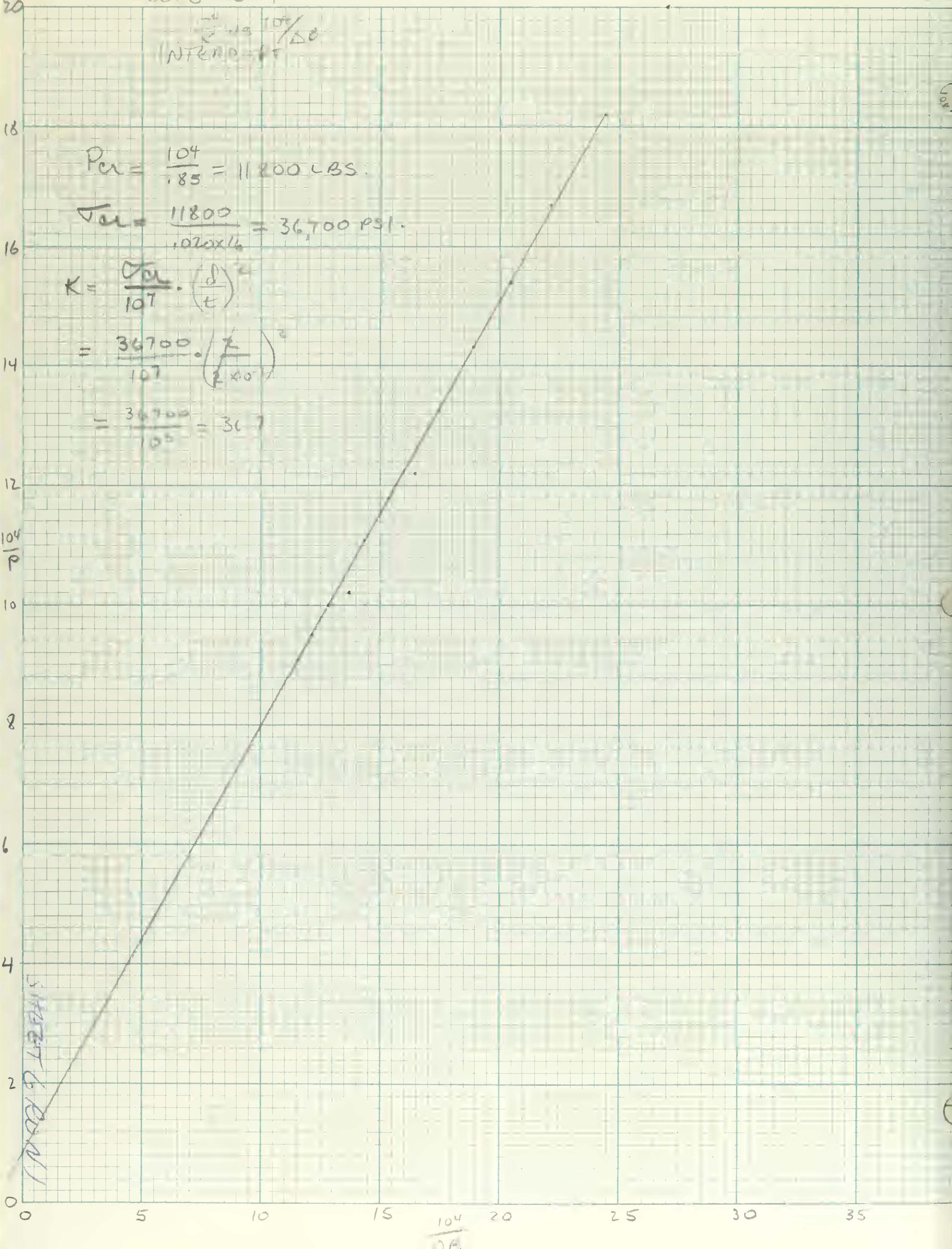


Sheet 6 Run 1.



TO DETERMINE BY INTERCEPT METHOD
10
20
30
40
$\frac{10^4}{P}$
0
10
20
30
40
50
60
70
80
100
SHEET 6 RUN I.

SHEET 6 RUN 1



$P_{cr} = \frac{10^4}{.85} = 11800$ LBS.

$\sigma_{cr} = \frac{11800}{.020 \times 16} = 36{,}700$ PSI.

$K = \frac{\sigma_{cr}}{10^7} \cdot \left(\frac{d}{t}\right)^2$

$= \frac{36700}{10^7} \cdot \left(\frac{2}{2 \times 10^{-2}}\right)^2$

$= \frac{36700}{10^3} = 36.7$

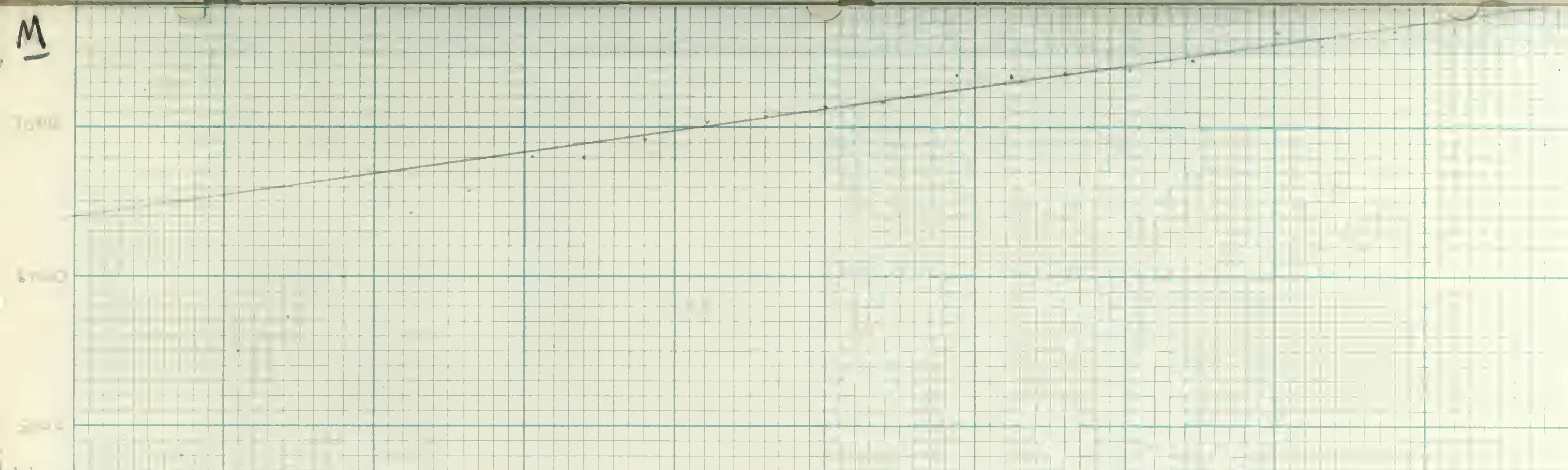
LOAD P	$10^4/P$	B	ΔB	$\frac{\Delta B}{P} \times 10^4$	$10^4/\Delta B$	T	ΔT	STRESS
0		620				760		
50		632	12	2400		763		
100		660	40	4000		758		
150		692	72	4800		750		
200		730	110	5500		742		
250		763	143	5720		733		
300		800	180	6000		724		
350		845	225	6430		715		
400		883	263	6580		708		
450		926	306	6800		700		
500		960	340	6800		692		
550		1000	380	6910		680		
600		1042	422	7030		671		
650		1080	460	7080		663		
700		1120	500	7140		653		
750		1158	538	7170		648		
800		1208	588	7350		633		
850		1244	624	7340		623		
900		1282	662	7360		[illegible]		
950		1322	702	7390		[illegible]		
1000		1365	745	7450		[illegible]		
1050		1421	801	7630		591		
1100		1451	832	7560		[illegible]		
1150		1500	880	7650		572		
1200		1540	920	7670		562		
1250								

LOAD P	$10^4/P$	B	ΔB	$\frac{\Delta B}{P} \times 10^4$	$10^4/\Delta B$	T	ΔT	STRESS
1300								

AP-450

SHEET 6 RUN 2 M.

M



$P_{cr} = \frac{1}{S_{slope}} = \frac{\delta\Delta B}{\frac{\ell^2}{P}\times 10^4} = \frac{1000}{(1440-6400)} \quad \frac{1000}{1440}\times 10^4 = 6944\ LBS$

$\sigma_{cr} = \frac{6944}{.320\times 10^{-6}} = \frac{6944}{32\times 10^{-3}} = 21{,}700\ LBS$

$K' = \frac{\sigma_{cr}}{E}\cdot\left(\frac{\ell}{t}\right)^2 = \frac{21{,}700}{10\times 10^6}\cdot\left(\frac{2}{2\times 10^{-3}}\right)^2 = \frac{21700}{10^3} = 21.7$

SHEET 6 REV. 2

No. 510

M

LOAD P	$10^4/P$	B	ΔB	$\frac{\Delta B \times 10^4}{P}$	$10^4/B$	T	ΔT	STRESS	
0		620	–						
50		638	18	3600		765			
100		663	43	4300		760			
150		690	70	4670		753			
200		728	108	5400		746			
[illegible]		763	143	5720		738			
300		800	180	6000		730			
350		842	222	6340		718			
400		880	260	6500		710			
450		922	302	6711		702			
500		960	340	6800		690			
550		1000	380	6909		684			
600		1043	423	7050		673			
650		1084	464	7138		668			
700		1122	502	7171		658			
750		1158	538	7173		648			
800		1199	579	7238		638			
850		1244	624	7341		628			
900		1285	665	7389		622			
950		1328	708	7453		610			
1000		1380	760	7600		600			
1050		1412	792	7543		590			
1100		1455	835	7590		580			
1150		1510	890	7740		570			
[illegible]		1550	930	7750		560			

LOAD P	$10^4/P$	B	ΔB	$\frac{\Delta B \times 10^4}{P}$	$\frac{10^4}{\Delta B}$	T	ΔT	STRESS
1300		1622	1002	7708				
1400		1700	1080	7714				
1500		1790	1170	7800				

RP-950

SHEET 6 RUN 3 N

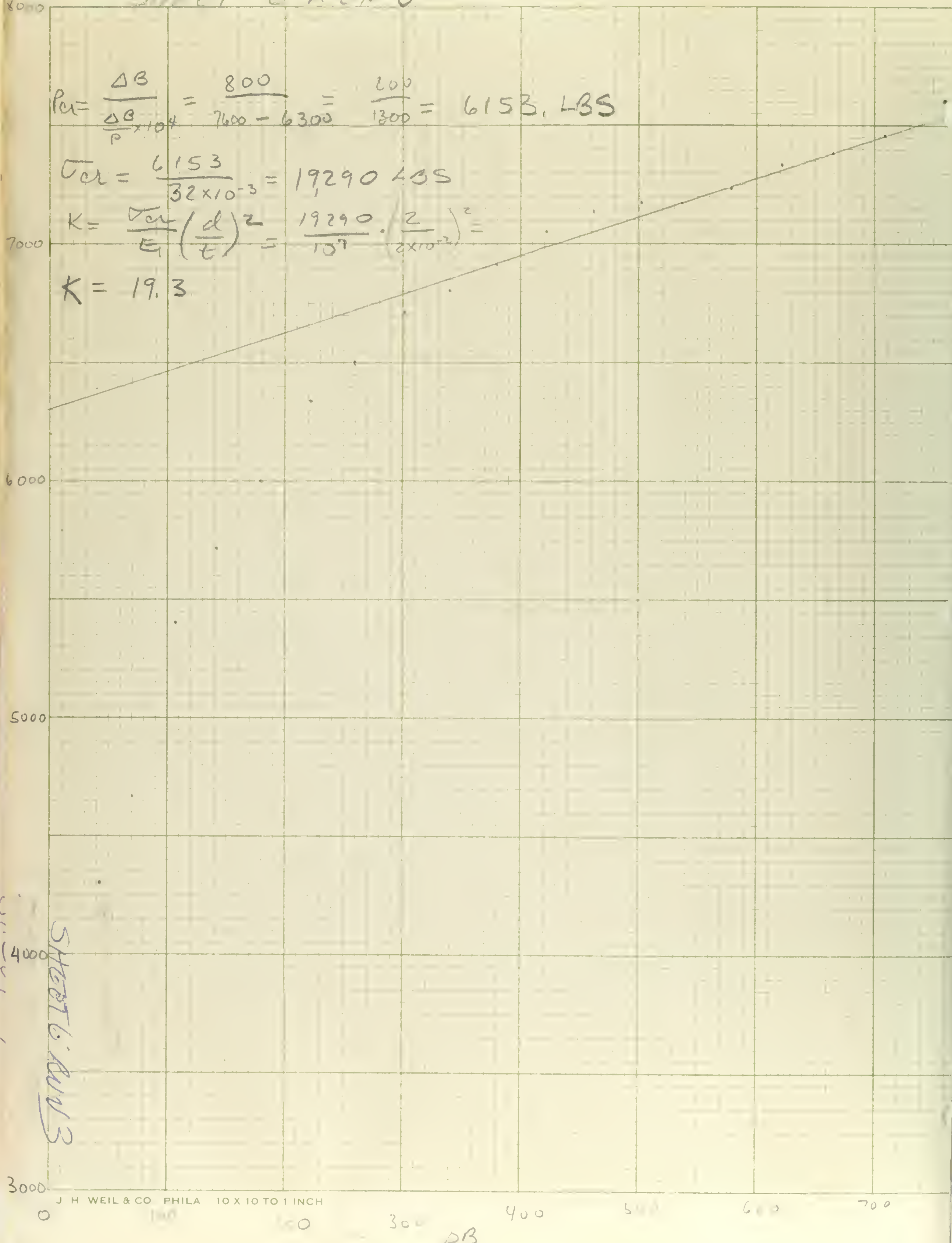
SHEET 6 RUN 3

$$P_{cr} = \frac{\Delta B}{\frac{\Delta B}{P} \times 10^4} = \frac{800}{7600 - 6300} = \frac{800}{1300} = 6153 \text{ LBS}$$

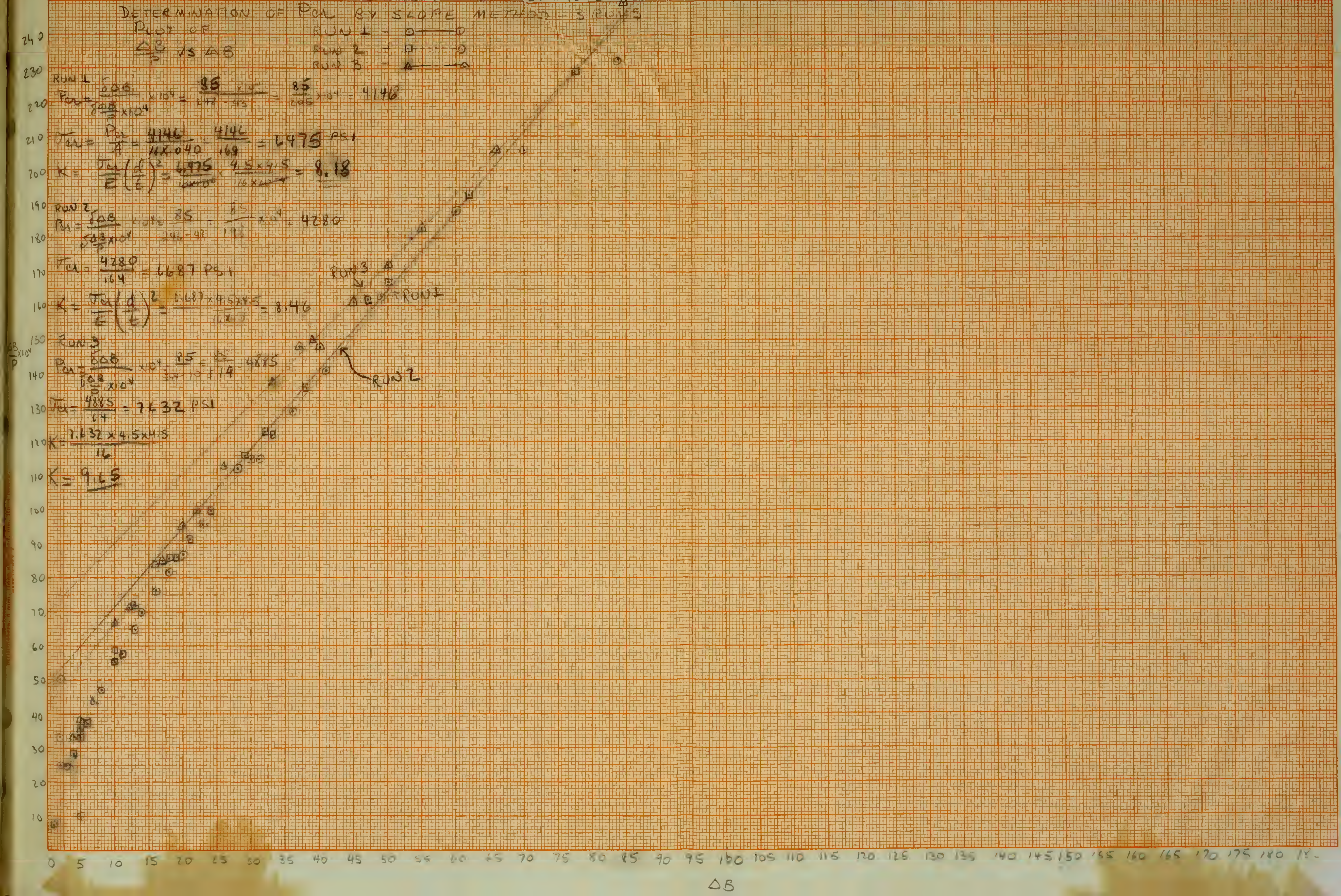
$$\sigma_{cr} = \frac{6153}{32 \times 10^{-3}} = 19{,}290 \text{ LBS}$$

$$K = \frac{\sigma_{cr}}{E}\left(\frac{d}{t}\right)^2 = \frac{19290}{10^7} \cdot \left(\frac{2}{2 \times 10^{-2}}\right)^2 =$$

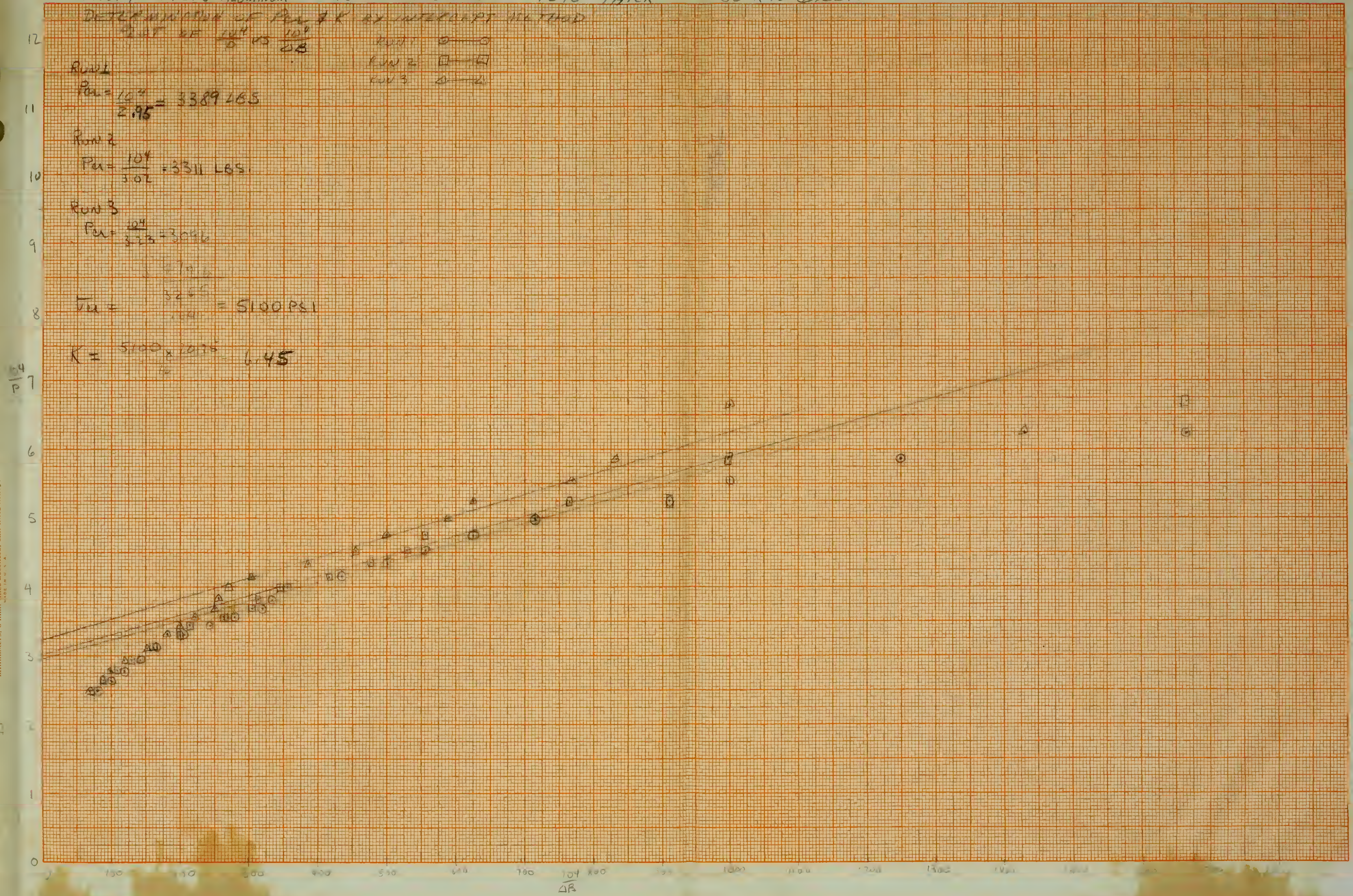
$$K = 19.3$$



SHEET NUMBER 7 24 ST 3 ALUMINUM 4.5" DIAMETER HOLE .040" THICK. 36" x 16" SHEET



SHEET 7 24ST3 ALUMINUM 4.5" DIAMETER HOLE .040" THICK 36" x 16" SHEET.



SHEET 7 RUN 1   16 X 36 X .040   WITH 4.5" HOLE   24S-T3 ALUM

$\frac{10^4}{P}$ VS $\frac{10^4}{\Delta B}$

$P_{cr_1} = \frac{10^4}{1.97} = 5076$ LBS $P_{cr_2} = \frac{10^4}{2.66} = 3759$

$\sigma_{cr_1} = \frac{5076}{.64} = 7930$ $\sigma_{cr} = \frac{3759}{.64} = 5880$

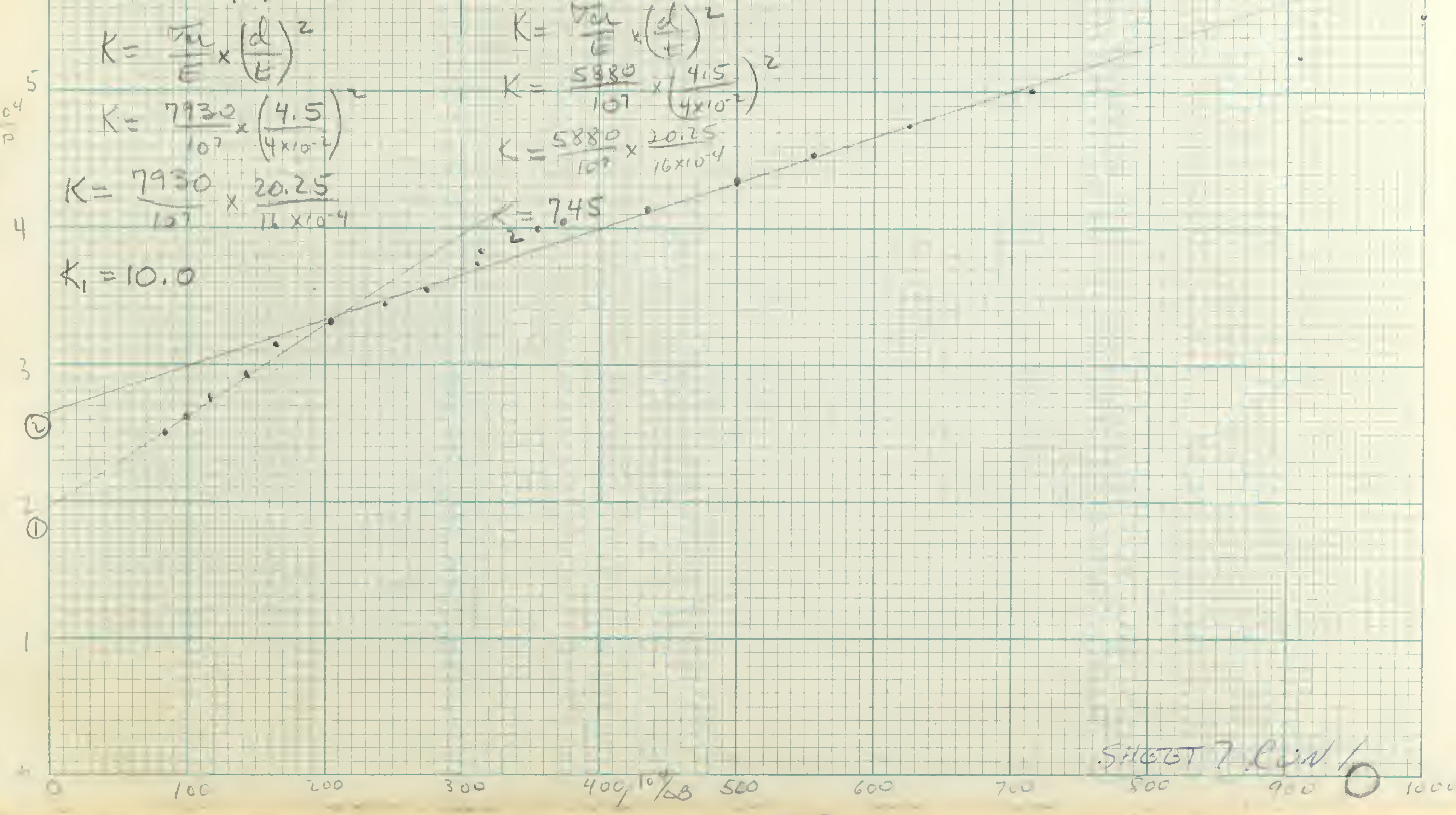
$K = \frac{\sigma_{cr}}{E} \times \left(\frac{d}{t}\right)^2$ $K = \frac{\sigma_{cr}}{E} \times \left(\frac{d}{t}\right)^2$

$K = \frac{7930}{10^7} \times \left(\frac{4.5}{4 \times 10^{-2}}\right)^2$ $K = \frac{5880}{10^7} \times \left(\frac{4.5}{4 \times 10^{-2}}\right)^2$

$K = \frac{7930}{10^7} \times \frac{20.25}{16 \times 10^{-4}}$ $K = \frac{5880}{10^7} \times \frac{20.25}{16 \times 10^{-4}}$

$K_2 = 7.45$

$K_1 = 10.0$



SHEET 7 RUN 1

P	$10^4/P$	B	ΔB	$\frac{10^4}{\Delta B}$	$\frac{\Delta B}{P} \times 10^4$	T	ΔT	STRESS PSI
0	—	1081	0					
100	100	1081	0					
200	50	1081	0					
300	33.3	1081	0					
400	25.0	1081	0					
500	20.0	1081	0					
600	16.7	1081	0					
700	14.3	1081	0					
800	12.5	1081	0					
900	11.1	1081	0					
1000	10.0	1081	0					
1100	9.09	1081	0					
1200	8.33	1084	3	3333	25			
1300	7.69	1082	1	10000	7.69			
1400	7.14	1086	5	2000	35.7			
1500	6.67	1086	5	2000	33.3			
1600	6.24	1087	6	1667	37.5			
1700	5.88	1089	8	1250	47.1			
1800	5.56	1091	10	1000	55.6			
1900	5.26	1092	11	909	57.9			
2000	5.00	1095	14	714	70.0			
2100	4.76	1097	16	625	76.2			
2200	4.54	1099	18	556	81.8			
2300	4.35	1101	20	500	87.0			
2400	4.16	1104	23	435	95.8			
2500	4.00	1109	28	357	112			

P	$\frac{10^4}{P}$	B	ΔB	$\frac{10^4}{\Delta B}$	$\frac{\Delta B}{P} \times 10^4$	T	ΔT	STRESS PSI
2600	3.84	1111	30	333	115			
2700	3.70	1112	31	323	115			
2800	3.57	1117	36	278	129			
2900	3.45	1122	41	244	141			
3000	3.33	1129	49	204	163			
3200	3.13	1140	60	167	188			
3400	2.94	1150	70	143	206			
3600	2.78	1164	84	119	233			
3800	2.63	1181	100	100	263			
4000	2.50	1205	124	80.6	310			
		1081 4						

RP-950

SHEET 7 RUN 1 0

SHEET 7 RUN 1. 16 × 36 × .040" WITH 4.5" HOLE 24 ST 3 ALUMINUM

DAVIS

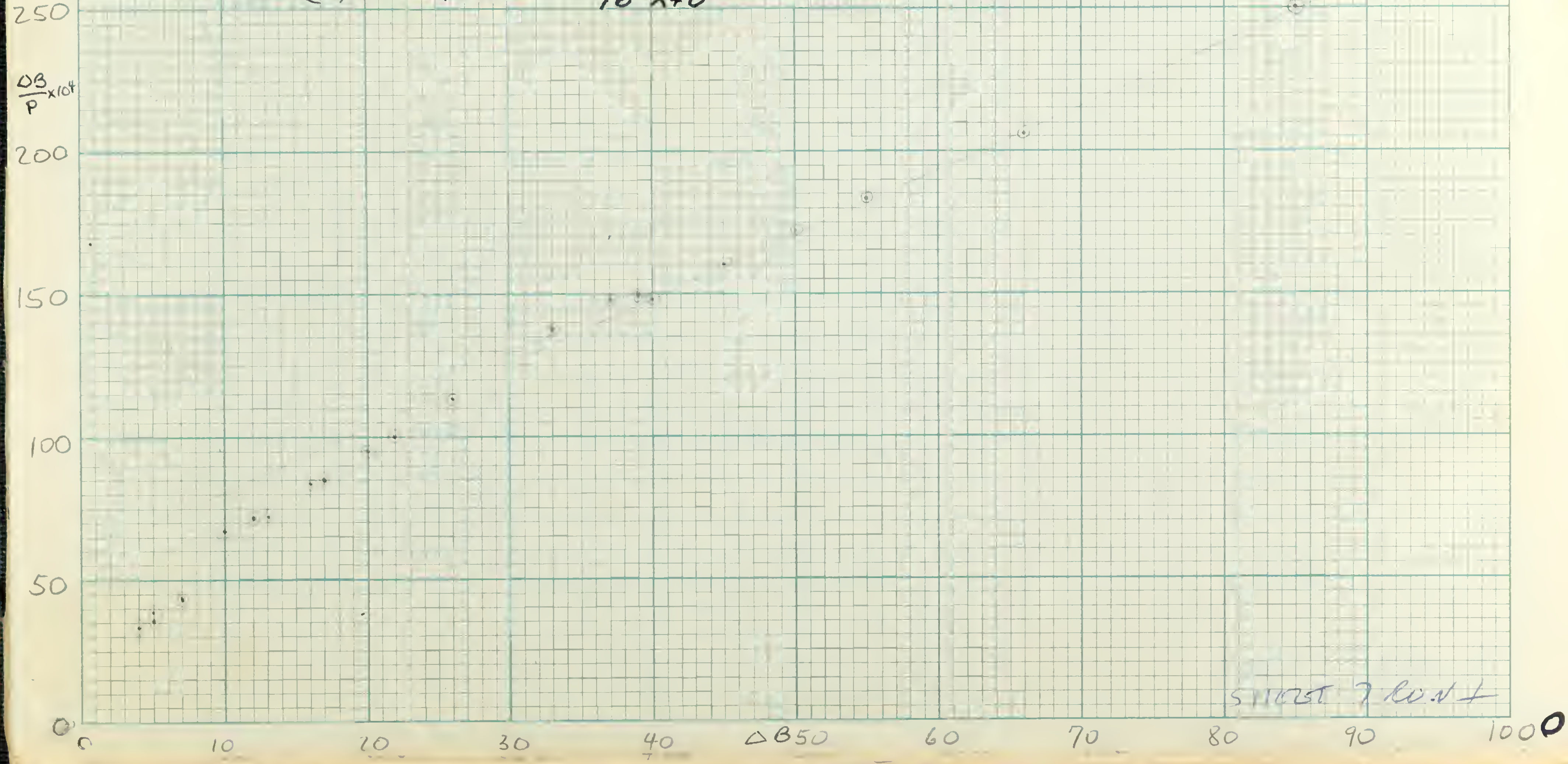
PLOT OF $\frac{\Delta B}{P} \times 10^4$ VS ΔB

TO DETERMINE K BY SLOPE METHOD

$$P_{cr} = \frac{1}{\text{SLOPE}} = \frac{\delta \Delta B}{\delta \frac{\Delta B}{P} \times 10^4} \times 10^4 = \frac{100}{283 - 58} = \frac{100}{225} \times 10^4 = 4444 \text{ LBS}$$

$$\sigma_{cr} = \frac{P_{cr}}{A} = \frac{4444}{16 \times .040} = \frac{111.1}{.16} = 7000 \text{ LBS/IN}^2$$

$$K = \frac{\sigma_{cr}}{E}\left(\frac{b}{t}\right)^2 = \frac{7\cancel{000}}{\cancel{10 \times 10^6}} \cdot \frac{4.5 \times 4.5}{16 \cancel{\times 10^{-4}}} = 8.86\cancel{87}$$



P	$10^4/P$	B	ΔB	$10^4/\Delta B$	$\frac{\Delta B}{P} \times 10^4$	T	ΔT	STRESS
0		1090	0					
100	100	1090	0					
200	50	1090	0		–			
300	33.3	1090	0		–			
400	25	1092	2		50			
500	20	1095	5		10			
600	16.7	1092	2		33.3			
700	14.3	1090	0		–			
800	12.5	1092	2		25			
900	11.1	1090	0	–	–			
1000	10.0	1092	2		20			
1100	9.09	1090	0	–	–			
1200	8.33	1090	0	–	–			
1300	7.69	1091	1	10000	7.69			
1400	7.14	1094	4	2500	28.6			
1500	6.67	1095	5	2000	33.3			
1600	6.24	1096	6	1670	37.5			
1700	5.88	1100	10	1000	58.8			
1800	5.56	1100	10	1000	55.6			
1900	5.26	1101	11	909	57.9			
2000	5.00	1103	13	769	65.0			
2100	4.76	1108	18	556	85.7			
2200	4.54	1109	19	526	86.4			
2300	4.35	1111	21	476	91.3			
2400	4.16	1114	24	416	100			
2500	4.00	1119	29	345	116			

P	$10^4/P$	B	ΔB	$10^4/\Delta B$	$\frac{\Delta B}{P} \times 10^4$	T	ΔT	STRESS
2600	3.84	1122	32	313	123			
2700	3.70	1123	33	303	122			
2800	3.57	1128	38	263	136			
2900	3.45	1137	47	213	162			
3000	3.33	1140	50	200	167			
3200	3.13	1152	62	161	193			
3400	2.94	1168	78	128	229			
3600	2.78	1182	92	109	255			
3800	2.63	1204	114	87.7	300			
4000	2.50	1230	140	71.4	350			

RP-450

SHEET 7 RUN 2 P

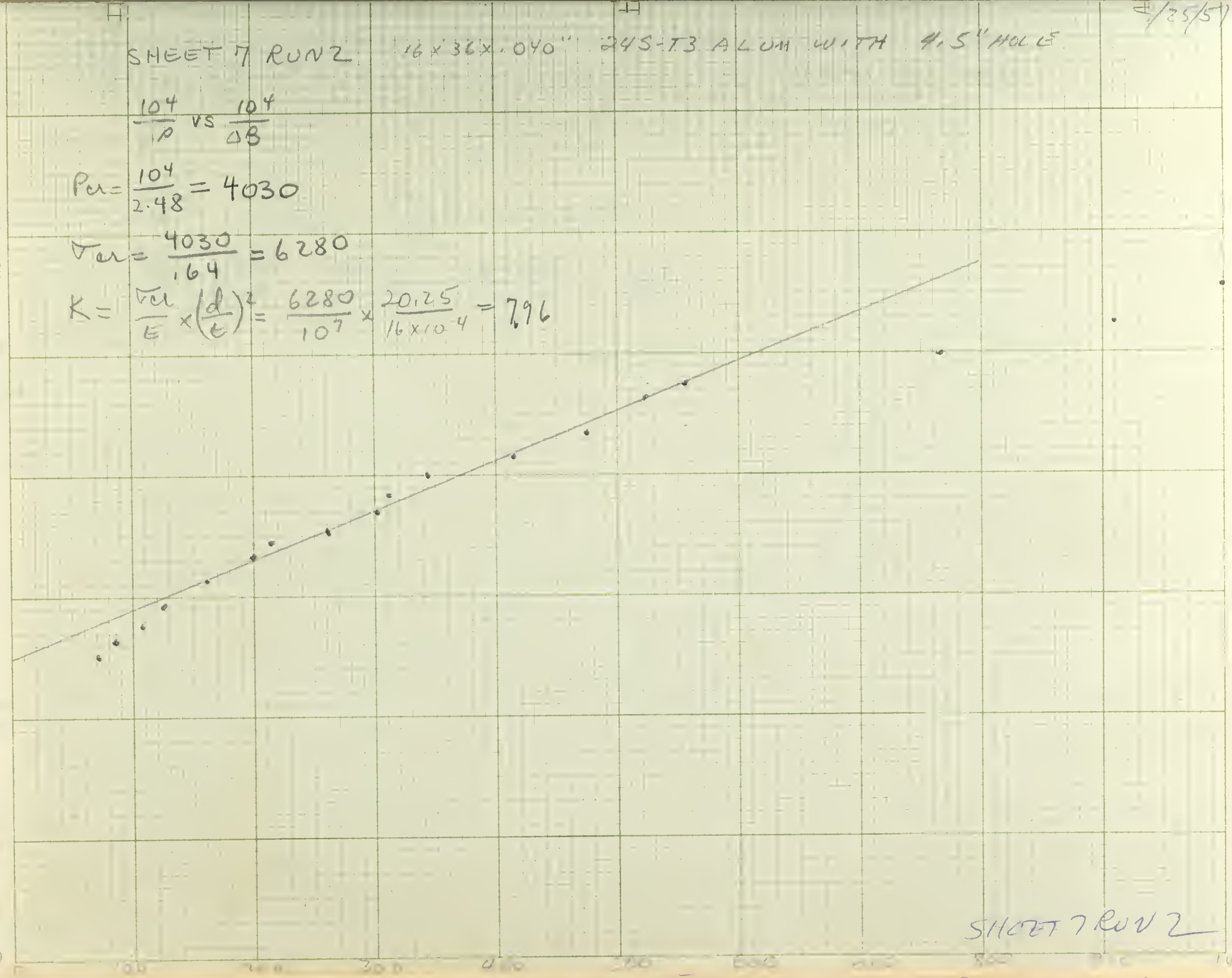
SHEET 7 RUN 2   16 x 36 x .040" 24S-T3 ALUM WITH 4.5" HOLE   4/25/51

$$\frac{10^4}{P} \text{ vs } \frac{10^4}{\Delta B}$$

$$P_{cr} = \frac{10^4}{2.48} = 4030$$

$$\sigma_{cr} = \frac{4030}{.64} = 6280$$

$$K = \frac{\sigma_{cr}}{E} \times \left(\frac{d}{t}\right)^2 = \frac{6280}{10^7} \times \frac{20.25}{16 \times 10^{-4}} = 7.96$$



SHEET 7 RUN 2

3/25/57
DAVIS.

SHEET 7 RUN 2 16 × 36 × .040" 4.5" HOLE 24ST6 T3 ALUM

PLOT OF $\frac{\Delta B}{P} \times 10^4$ VS ΔB TO DETERMINE K BY SLOPE METHOD

$$P_{cr} = \frac{1}{\text{SLOPE}} = \frac{\delta \Delta B}{\delta \frac{\Delta B}{P} \times 10^4} \times 10^4 = \frac{100 \times 10^4}{283 - 45} = \frac{10^6}{238} = 4202 \text{ LBS}$$

$$\sigma_{cr} = \frac{P_{cr}}{A} = \frac{4202}{16 \times .040} = \frac{4202}{.64} = 6565 \text{ PSI.}$$

$$K = \frac{\sigma_{cr}}{E} \cdot \left(\frac{d}{t}\right)^2 = \frac{6565}{10^7} \cdot \frac{4.5 \times 4.5}{16 \times 10^{-4}} = \underline{\underline{8.32}}$$

$\frac{\Delta B}{P} \times 10^4$: 0, 50, 100, 150, 200, 250, 300, 350

ΔB: 0, 10, 20, 30, 40, 50, 60, 70, 80, 90, 100

SHEET 7 RUN 2

SHEET 7 RUN 2

BEE 10 x 10

P	$10^4/P$	R	ΔB	$10^4/\Delta B$	$\frac{\Delta B}{P}\times 10^4$	T	ΔT	Stress PSI
0	—	1095	0					
100	100	1098	3					
200	50	1100	5					
300	33.3	1098	3					
400	25.0	1099	4					
500	20.0	1098	3					
600	16.7	1100	5					
700	14.3	1100	5					
800	12.5	1100	5					
900	11.1	1098	3					
1000	10.0	1098	3					
1100	9.09	1095	0	—	—			
1200	8.33	1099	4	2500	33.3			
1300	7.69	1100	5	2000	38.5			
1400	7.14	1100	5	2000	35.7			
1500	6.66	1105	10	1000	66.7			
1600	6.25	1102	7	1429	43.8			
1700	5.88	1107	12	833	70.6			
1800	5.56	1108	13	769	72.2			
1900	5.26	1111	16	625	84.2			
2000	5.00	1112	17	588	85.0			
2100	4.76	1115	20	500	95.2			
2200	4.54	1117	22	454	100			
2300	4.35	1121	26	385	113			
2400	4.17	1128	33	303	138			
2500	4.00	1132	37	270	148			

P	$10^4/P$	B	ΔB	$10^4/\Delta B$	$\frac{\Delta B}{P}\times 10^4$	T	ΔT	Stress
2600	3.85	1134	39	256	150			
2700	3.70	1135	40	250	148			
2800	3.57	1140	45	222	161			
2900	3.45	1145	50	200	172			
3000	3.33	1150	55	182	183			
3200	3.13	1161	66	152	206			
3400	2.94	1180	85	118	250			
3600	2.78	1196	101	99.1	281			
3800	2.63	1216	121	82.6	318			
4000	2.50	1240	145	69.0	363			

RP-450

SHEET 7 RUN 3

Q

SHEET 7 RUN 3

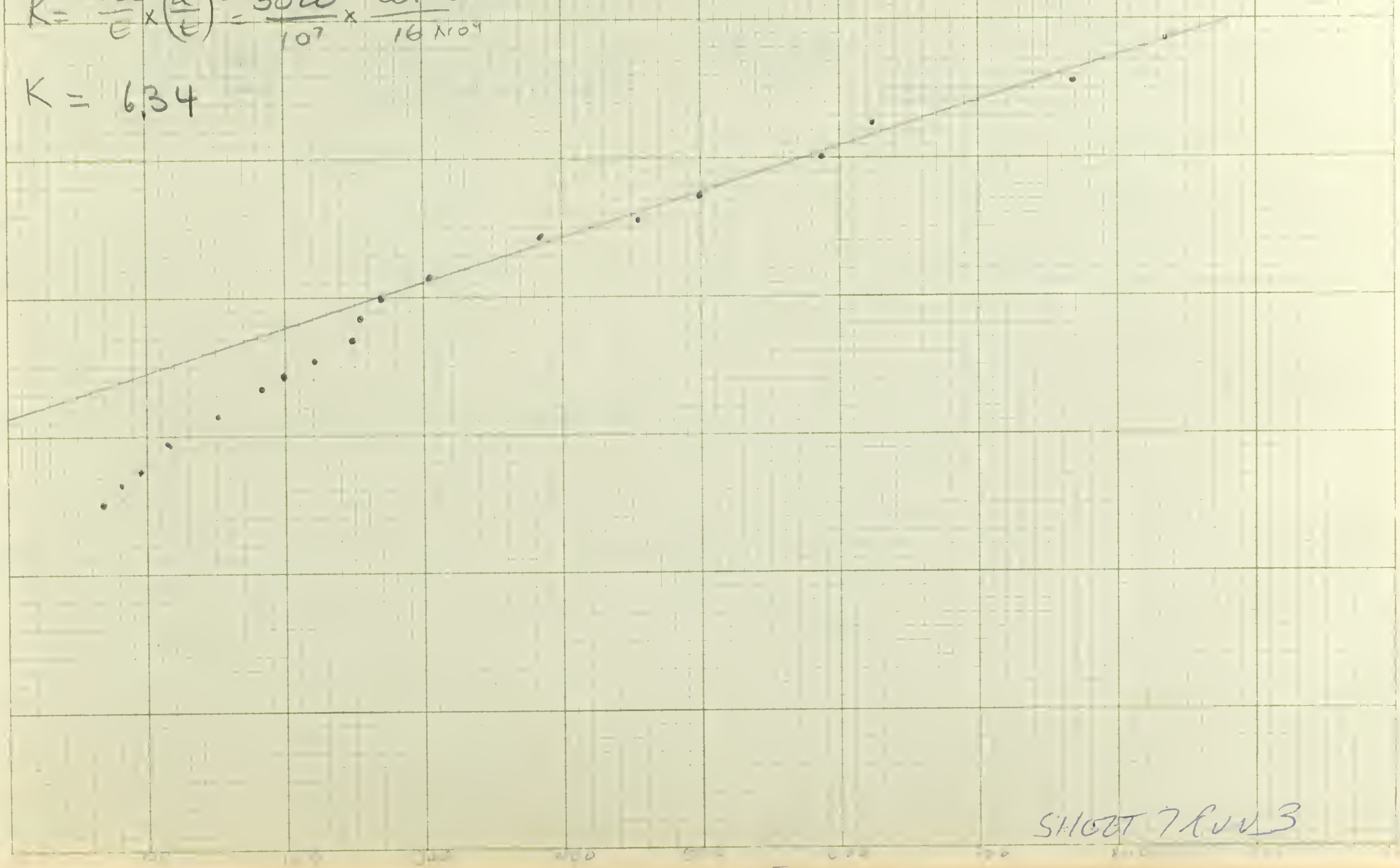
$\frac{10^4}{P}$ vs $\frac{10^4}{DB}$

$P_{cr} = \frac{10^4}{3.12} = 3205$

$\sigma_{cr} = \frac{3205}{.164} = 5020$

$K = \frac{\sigma_{cr}}{E} \times \left(\frac{d}{t}\right)^2 = \frac{5020}{10^7} \times \frac{20.25}{16 \times 10^{-4}}$

$K = 6.34$



SHEET 7 RUN 3

Q

SHEET 7 RUN 3 16 x 36 x .040 24ST6 T3 ALUM WITH 4.5" HOLE

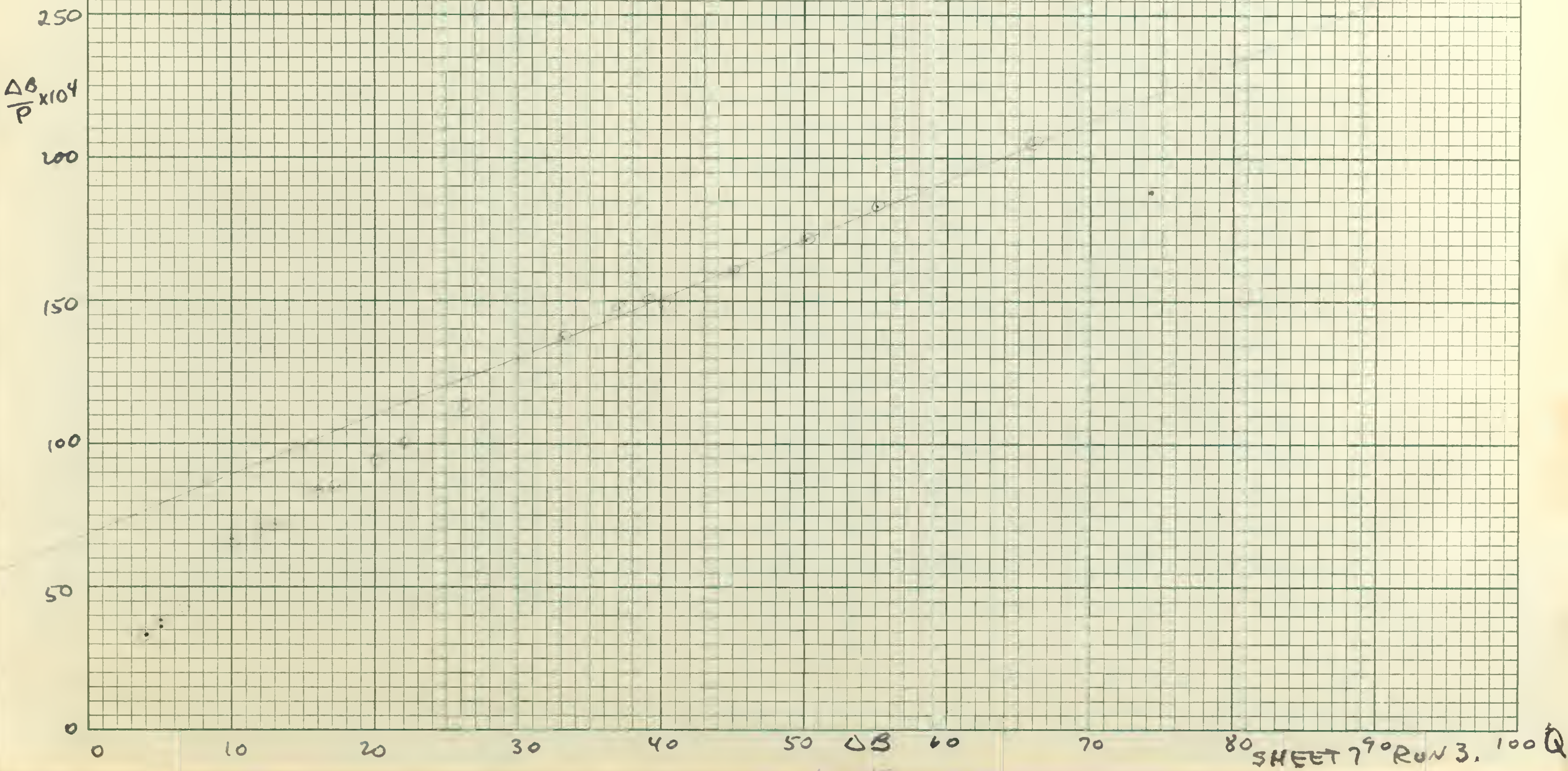
3/25/57
DAVIS

PLOT OF $\frac{\Delta B}{P} \times 10^4$ VS ΔB TO DETERMINE ~~SLOPE~~ P_{cr} BY ~~SLOPE~~ METHOD

$$P_{cr} = \frac{1}{\text{SLOPE}} = \frac{\delta \Delta B \times 10^4}{\delta \frac{\Delta B}{P} \times 10^4} = \frac{10^6}{275 - 69} = \frac{10^6}{206} = 4854 \text{ LBS}$$

$$\sigma_{cr} = \frac{P_{cr}}{A} = \frac{4854}{.64} = 7584 \text{ PSI}$$

$$K = \frac{\sigma_{cr}}{E} \cdot \left(\frac{d}{t}\right)^2 = \frac{7.584}{10^7} \cdot \frac{81}{4 \cdot 16 \times 10^{-4}} = \frac{7.584 \times 81}{64} = \underline{\underline{9.60}}$$



BEE 10 x 10

SHEET 7 RUN 3.

Q

P	$\frac{10^4}{P}$	B	ΔB	$\frac{\Delta B}{P} \times 10^4$	$\frac{10^4}{\Delta B}$	T	ΔT	STRESS	P	$\frac{10^4}{P}$	B	ΔB	$\frac{\Delta B}{P}$	$\frac{10^4}{\Delta B}$	T	ΔT	STRESS
0		2962	0			200			2600	3.84	2662	300	1154.	33.3	214		
100	100	2962	0			240			2700	3.70	2600	362	1341.	27.6	256		
200	50	2975	-13			280			2800	3.57	2528	434	155.0	23.0	298		
300	33.3	2970	-8			326			2900	3.45	2449	513	1769	19.5	338		
400	25	2980	-18			365			3000	3.33	2365	597	1990	16.8	379		
500	20	2965	-3			400			3100	3.23	2281	671	2165	14.9	423		
600	16.7	2962	0			439			3200	3.13	2185	777	2428	12.9	465		
700	14.3	2960	+2	28.57	5000	478			3300	3.03	2096	866	2624	11.5	508		
800	12.5	2960	+2	25.00	5000	512			3400	2.94	2000	962	2829	10.4	550		
900	11.1	2952	+10	111.10	1000	550			3500	2.86	1905	1057	3020	9.43	598		
1000	10.0	2950	12	120.00	833	589			3600	2.78	1826	1136	3155	8.77	634		
1100	9.09	2950	12	109.1	833	628			3700	2.70	1734	1228	3318	8.13	682		
1200	8.33	2942	20	166.7	500	663			3800	2.63	1648	1314	3458	7.63	728		
1300	7.69	2932	30	230.7	333	702			3900	2.56	1568	1394	3574	7.19	770		
1400	7.14	2932	30	214.3	333	745			4000	2.50	1490	1472	3680	6.80	812		
1500	6.67	2920	42	280.0	238	780			4100	2.44	1409	1553	3788	6.45	856		
1600	6.24	2919	43	268.8	233	819			4200	2.38	1325	1637	3898	6.10	904		
1700	5.88	2908	54	317.6	185	854			4300	2.32	1255	1707	3970	5.85	945		
1800	5.56	2900	62	344.4	161	892			4400	2.27	1180	1782	4050	5.62	990		
1900	5.26	2880	82	431.6	122	930			4500	2.22	1100	1862	4138	5.38	1038		
2000	5.00	2872	90	450.0	111	972			4600	2.17	1033	1929	4193	5.18	1080		
2100	4.76	2855	107	509.5	93.5	1012			4700	2.13	965	1997	4248	5.00	1120		
2200	4.54	2830	132	600.0	75.8	052			4800	2.08	892	2070	4312	4.83	1172		
2300	4.35	2802	160	695.7	62.5	090			4900	2.04	812	2150	4388	4.65	1225		
2400	4.16	2769	193	804.2	51.8	132			5000	2.00	752	2210	4420	4.52	1272		
2500	4.00	2725	237	948.0	42.2	172											

RP-450

SHEET 8 RUN 4 ✓

$$K = \frac{\sigma_{cr}}{E} \cdot \left(\frac{d}{t}\right)^2$$

$\frac{1000}{16}$

$=$

$$\frac{10^5}{16 \times 10 \times \cancel{10}} \left(\frac{6 \cdot 6}{16 \times \cancel{64}} \right)$$

$$\left(\frac{9}{64}\right) 10^2$$

$$\begin{array}{r} .1406 \\ 64 \overline{)\,900} \\ 64 \\ \hline 260 \\ 256 \\ \hline 400 \end{array}$$

$$\begin{array}{r} .375 \\ 16 \overline{)\,6.0} \\ 48 \\ \hline 120 \\ 112 \\ \hline 80 \end{array}$$

SHEET 8 ROD 1 24ST3 ALUMINUM 1/16 X 36 X .040

DETERMINATION OF P_{cr} & K BY SLOPE METHOD

PLOT OF $\frac{\Delta B}{P} \times 10^{4}$ VS ΔB

$P_{cr} = \frac{\delta\, \Delta B}{\delta \frac{\Delta B}{P}} \times 10^{-4} = \frac{1100 - 300}{.986 - [illegible]} \times 10^{4} = \frac{800}{[illegible]} \times 10^{4}$

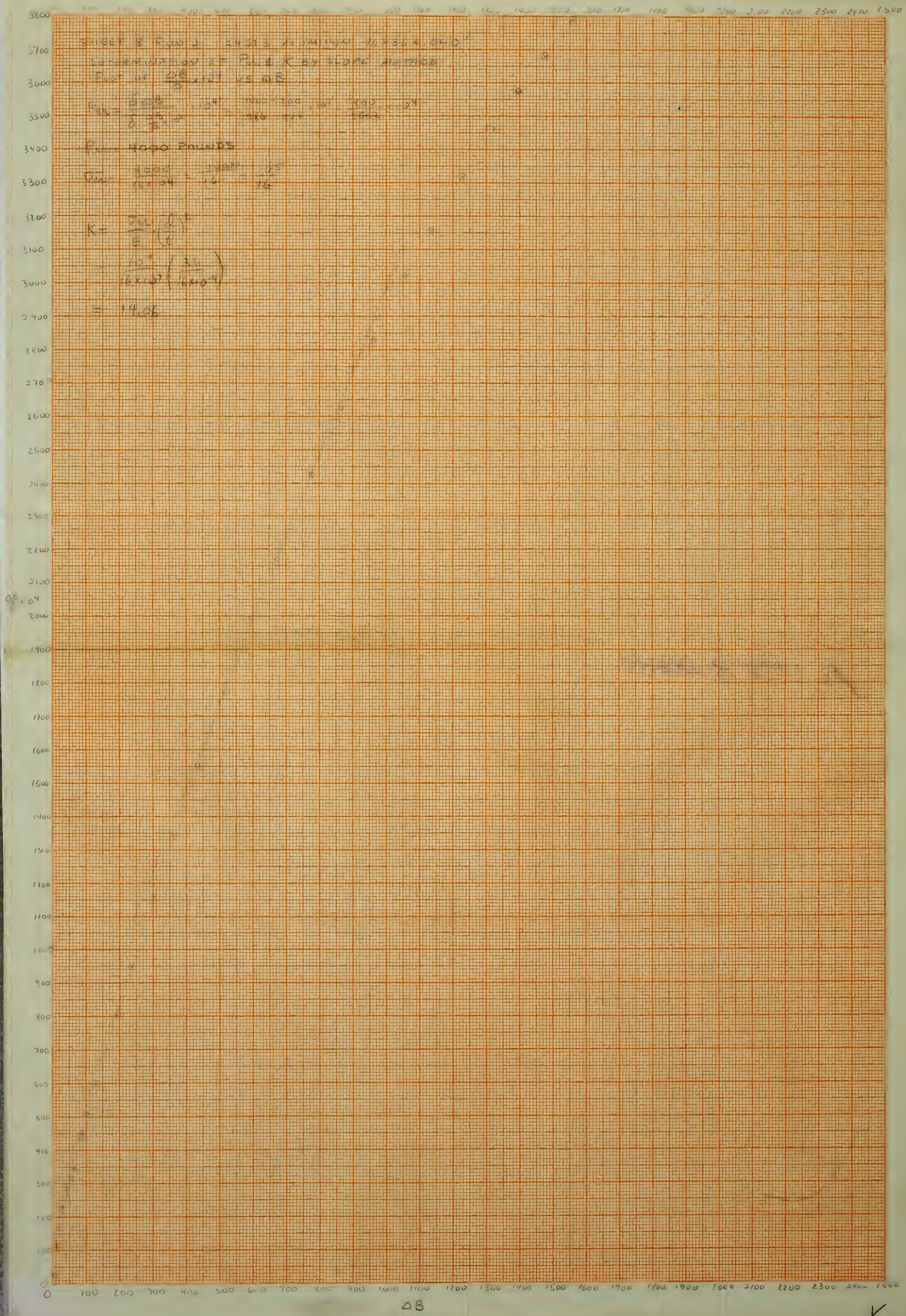
P_{cr} — 4000 POUNDS

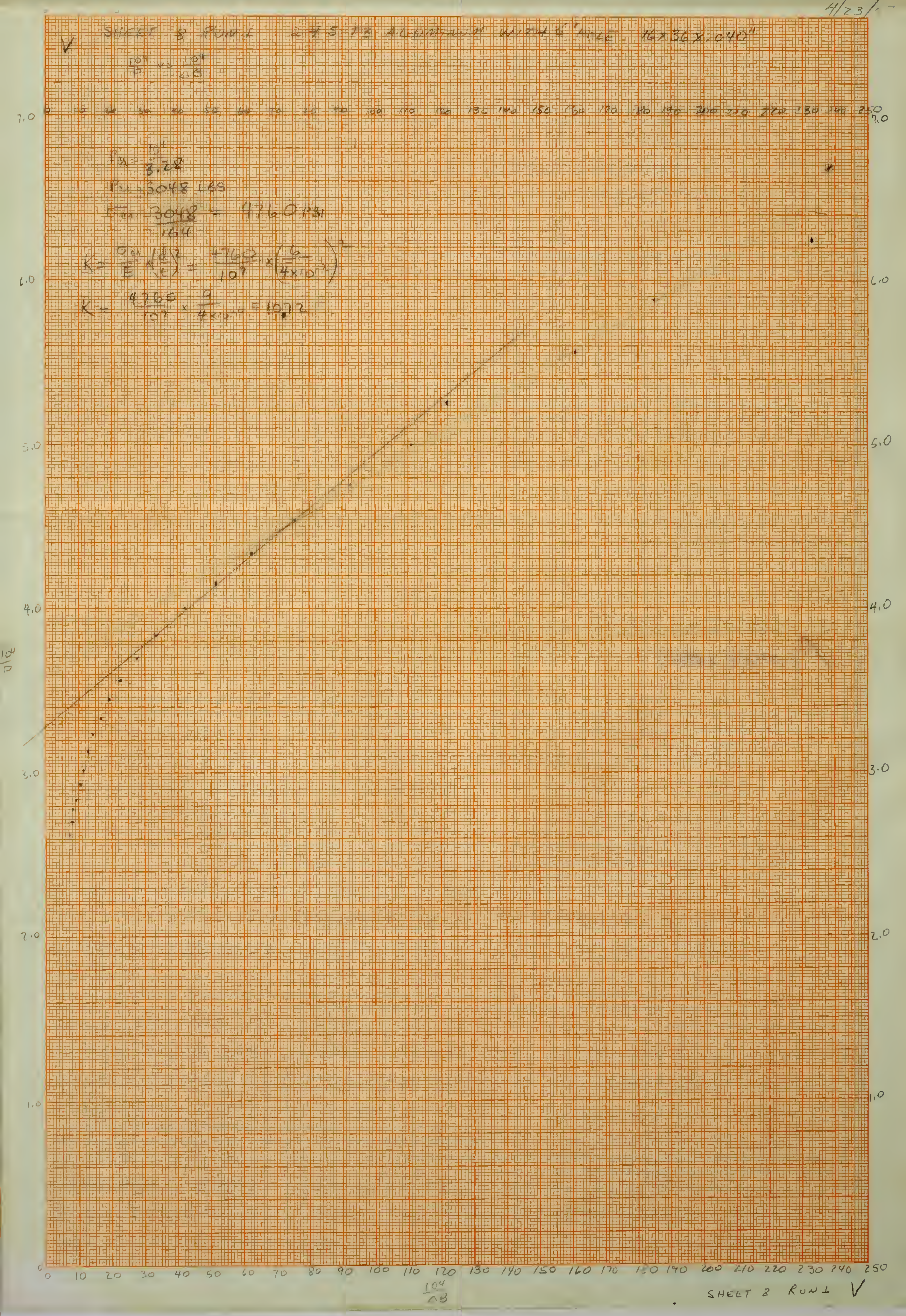
$\sigma_{cr} = \frac{4000}{16 \times .04} = \frac{[illegible]}{16} = \frac{[illegible]}{16}$

$K = \frac{\sigma_{cr}}{E}\left(\frac{L}{t}\right)^2$

$= \frac{[illegible]}{16 \times 10^{7}}\left(\frac{36}{4 \times 10^{-4}}\right)$

$= 14.06$





4/23/
SHEET 8 RUN I 24S T3 ALUMINUM WITH 6" HOLE 16 x 36 x .040"
$\frac{10^4}{P}$ vs $\frac{10^4}{\Delta B}$
$P_{cr} = \frac{10^4}{3.28}$
$P_u = 3048$ LBS
$\sigma_u = \frac{3048}{.64} = 4760$ PSI
$K = \frac{\sigma_u}{E} \times \left(\frac{b}{t}\right)^2 = \frac{4760}{10^7} \times \left(\frac{6}{4 \times 10^{-2}}\right)^2$
$K = \frac{4760}{10^7} \times \frac{9}{4 \times 10^{-4}} = 10.72$
$\frac{10^4}{P}$
$\frac{10^4}{\Delta B}$
SHEET 8 RUN I

P	$10^4/P$	B	ΔB	$\frac{\Delta B}{P} \times 10^4$	$\frac{10^4}{\Delta B}$	T	ΔT	STRESS
0		2930	0			1178.		
[illegible]		2950	-20			1218		
[illegible]		2942	-18			1261		
[illegible]		2943	-13			1305		
[illegible]		2938	-8			1344		
[illegible]		2935	-5			1378		
[illegible]		2930	0	—		1422		
[illegible]		2933	-3			1460		
[illegible]	12.5	2922	+8	100	1250	1498		
[illegible]	11.1	2920	10	111.1	1000	1532		
[illegible]	10.0	2912	18	180.0	556	1572		
[illegible]	9.09	2909	21	190.9	476	[illegible]		
[illegible]	8.33	[illegible]	25	208.3	400	1646		
[illegible]	7.69	2900	30	230.7	333	1683		
[illegible]	7.14	2896	34	242.9	294	1723		
[illegible]	6.67	2889	41	273.3	244	1762		
[illegible]	6.24	2885	45	281.2	222	1800		
[illegible]	5.88	2872	58	341.1	173	1835		
[illegible]	5.56	2870	60	333.3	167	1874		
[illegible]	5.26	2855	75	394.7	133	1912		
[illegible]	5.00	2842	88	440.0	114	1950		
[illegible]	4.76	2814	116	552.3	86.2	1987		
[illegible]	4.54	2800	130	590.9	76.9	—		
[illegible]	4.35	2762	168	730.4	59.5	2067		
[illegible]	4.16	2735	195	812.5	51.3	[illegible]		
[illegible]	4.00	2682	248	992.0	40.3	2150		

P	$10^4/P$	B	ΔB	$\frac{\Delta B}{P}$	$\frac{10^4}{\Delta B}$	T	ΔT	STRESS
[illegible]	3.84	2626	304	1169	32.9	2190		
[illegible]	3.70	2561	369	1367	27.1	2231		
2800	3.57	2475	455	1625	21.9	2274		
2900	3.45	2405	525	1810	19.0	2315		
[illegible]	3.33	2310	620	2067	16.1	2358		
3100	3.23	2212	718	2316	13.9	2400		
3200	3.13	2118	812	2537	12.3	2443		
3300	3.03	2025	905	2742	11.0	2486		
3400	2.94	1960	970	2853	10.3	2530		
3500	2.86	1862	1068	3051		2572		
3600	2.78	1778	1152	3200		2616		
3700	2.70	1691	1239	[illegible]		2656		
3800	2.63	1600	1330	3500		2702		
[illegible]	2.56	1510	1420	3641		2746		
400	2.50	1440	1490	3725		2785		
4100	2.44	1352	1578	3849		2832		
4200	2.38	1270	1660	3952		2879		
4300	2.32	1190	1740	4047		2925		
4400	2.27	1128	1802	4095		2965		
[illegible]	2.22	1050	1880	4177		3000		
[illegible]	2.17	974	1956	4252		3046		
4700	2.13	891	2039	4338		3086		
4800	2.08	822	2108	[illegible]		3097		
4900	2.04	750	2180	4449		3114		
5000	2.00	668	2262	4524		3245		

RR

SI/CZT 8 RUN 2

RP-450

TIME EST PER SHEET

2.5 HRS [illegible] [illegible]
[illegible] ERRORS

2.0 HRS FOR ERRORS

2.0 HRS COMPUTATIONS

.5 HRS PLOTTING DATA

.3 HRS COMPUTER I/O

7.3 HRS PER SHEET.

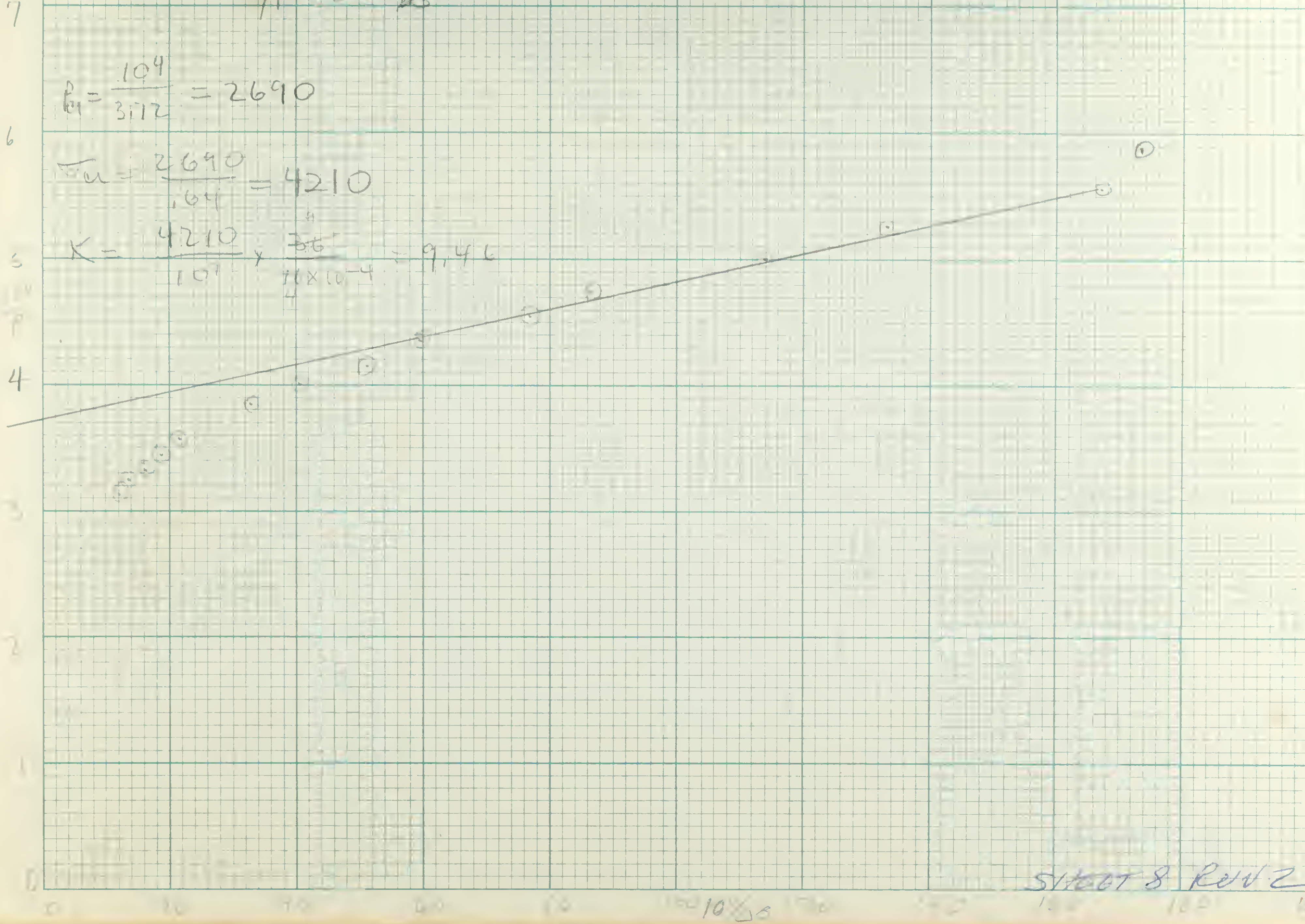
SHEET 8 RUN 2 24S-T3 ALUM 16 X 36 X .040" WITH 6" HOLE 7/24

$10^4/P$ vs $10^4/B$

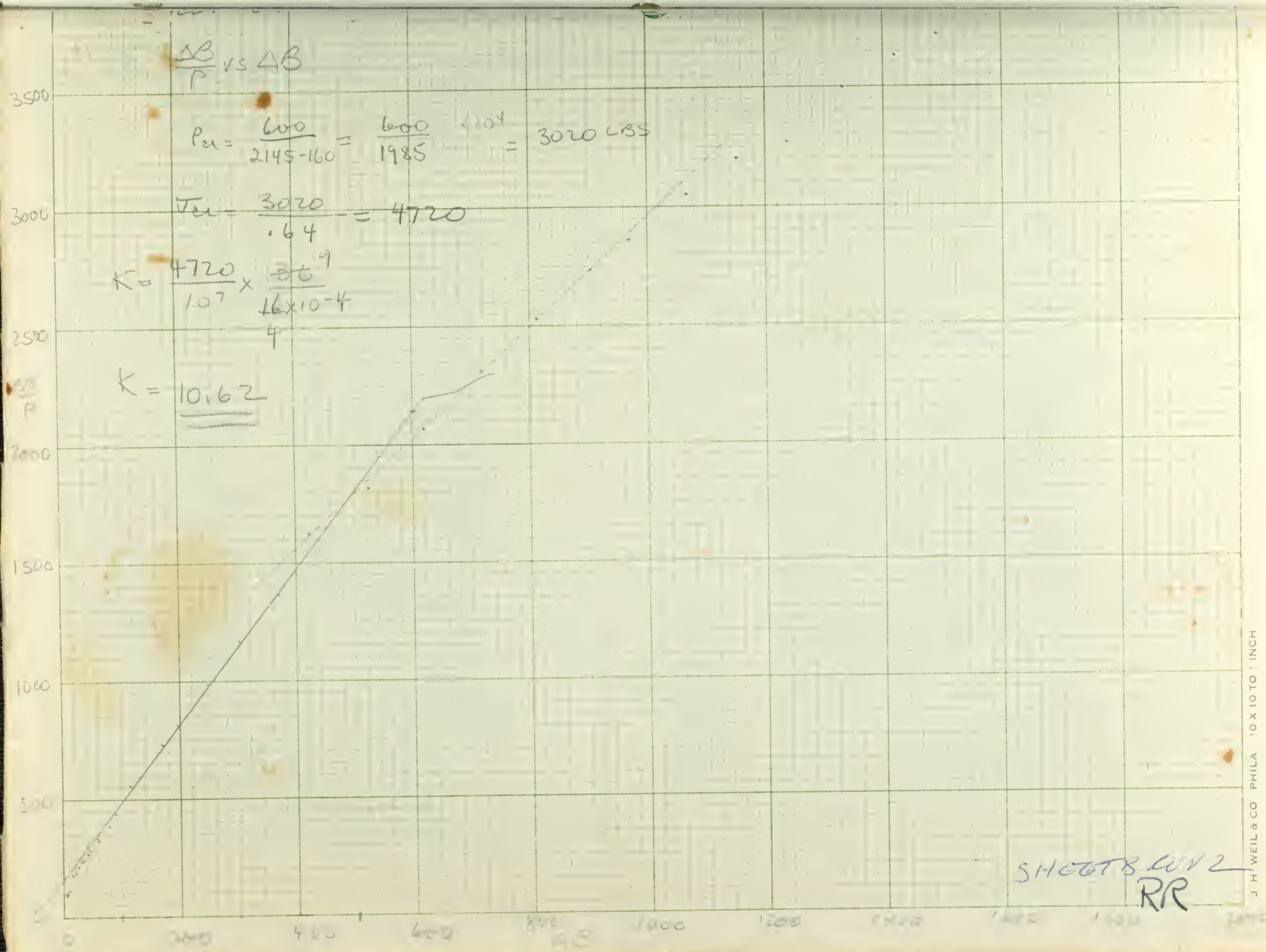
$P_u = \frac{10^4}{3.72} = 2690$

$\sigma_u = \frac{2690}{.64} = 4210$

$K = \frac{4210}{10^7} \times \frac{36^4}{16 \times 10^{-4}} = 9.46$



SHEET 8 RUN 2



$\frac{\Delta B}{P}$ vs ΔB

$P_{cr} = \frac{600}{2145-160} = \frac{600}{1985} \times 10^4 = 3020$ LBS

$\sigma_{cr} = \frac{3020}{.64} = 4720$

$K = \frac{4720}{10^7} \times \frac{36^9}{\frac{16 \times 10^{-4}}{4}}$

$K = \underline{\underline{10.62}}$

SHEET 8 OF 2
RR

P	$\frac{10^4}{P}$	B	ΔB	$\frac{ΔB}{P}$	$\frac{10^4}{ΔB}$	T	ΔT	Stress PSI
0		2975	0			1125		
100		2982	-7			1165		
200		2982	-7			1198		
300		2982	-7			1240		
400		2982	-7					
500		2981	-6			1320		
600		2978	-3			1458		
700	14.3	2972	+3	42.85	3333	1390		
800	12.5	2972	+3	37.50	3333	1432		
900	11.1	2958	17	188.0	588	1470		
1000	10.0	2968	7	70.0	1430	1508		
1100	9.09	2952	23	[illegible]	435	1545		
1200	8.33	2950	25	208.3	400	1582		
1300	7.69	2952	23	[illegible]	435	1620		
1400	7.14	2935	40	[illegible]	250	1660		
1500	6.67	2932	43	[illegible]	232	1700		
1600	6.24	2925	50	312.5	[illegible]	1740		
1700	5.88	2910	65	382.3	154	1775		
1800	5.56	2908	67	372.2	149	1812		
1900	5.26	2884	91	[illegible]	110	1855		
2000	5.00	2872	103	[illegible]	97.1	1894		
2100	4.76	2855	120	571.4	83.3	1930		
2200	4.54	2829	146	[illegible]	68.5	1970		
2300	4.35	2800	175	760.8	57.1	2005		
2400	4.16	2775	200	833.3	50.0	—		
2500	4.00	2722	253	1012	39.5	2093		

P	$\frac{10^4}{P}$	B	ΔB	$\frac{ΔB}{P}$	$\frac{10^4}{ΔB}$	T	ΔT	Stress PSI
2600	3.84	2665	310	1192	32.3	2132		
2700	3.70	2600	375	1389	[illegible]	2172		
2800	3.57	2531	444	1586	22.5	2215		
2900	3.45	2458	517	1783	19.3	2256		
3000	3.33	2370	605	2016	16.5	2300		
3100		2261	714	2303	14.0	2346		
3200	3.13	2175	800	2500	12.5	2385		
3300		2100	875	2652	11.4	2428		
3400	2.94	1972	1003	2950		2468		
3500		1876	1099	3140	10.9	2516		
3600	2.78	1792	1183	[illegible]	8.47	2557		
3700		1702	1273	3441	[illegible]	2601		
3800	2.63	1615	1360	[illegible]	27.1	2646		
3900		1532	1443	3700	[illegible]	2690		
4000	2.50	1455	1520	[illegible]	[illegible]	2732		
4100		1368	1607	[illegible]	[illegible]	2778		
4200		1288	1687	[illegible]	24.8	2826		
4300		1202	1773	[illegible]	[illegible]	2871		
4400		1128	1847	[illegible]	[illegible]	2913		
4500		1058	1917	[illegible]	[illegible]	2960		
4600		979	1996	[illegible]	[illegible]	3005		
4700		906	2069	[illegible]	22.7	3050		
4800		832	2143	4465	[illegible]	3198		
4900		762	2213	[illegible]	19.1	3143		
5000	2.00	670	2305	4610	21.7	3200		

RP-450

SHEET 8 RUN 3 Y

4/25

$\frac{10^4}{P}$ vs $\frac{10^4}{\Delta B}$.

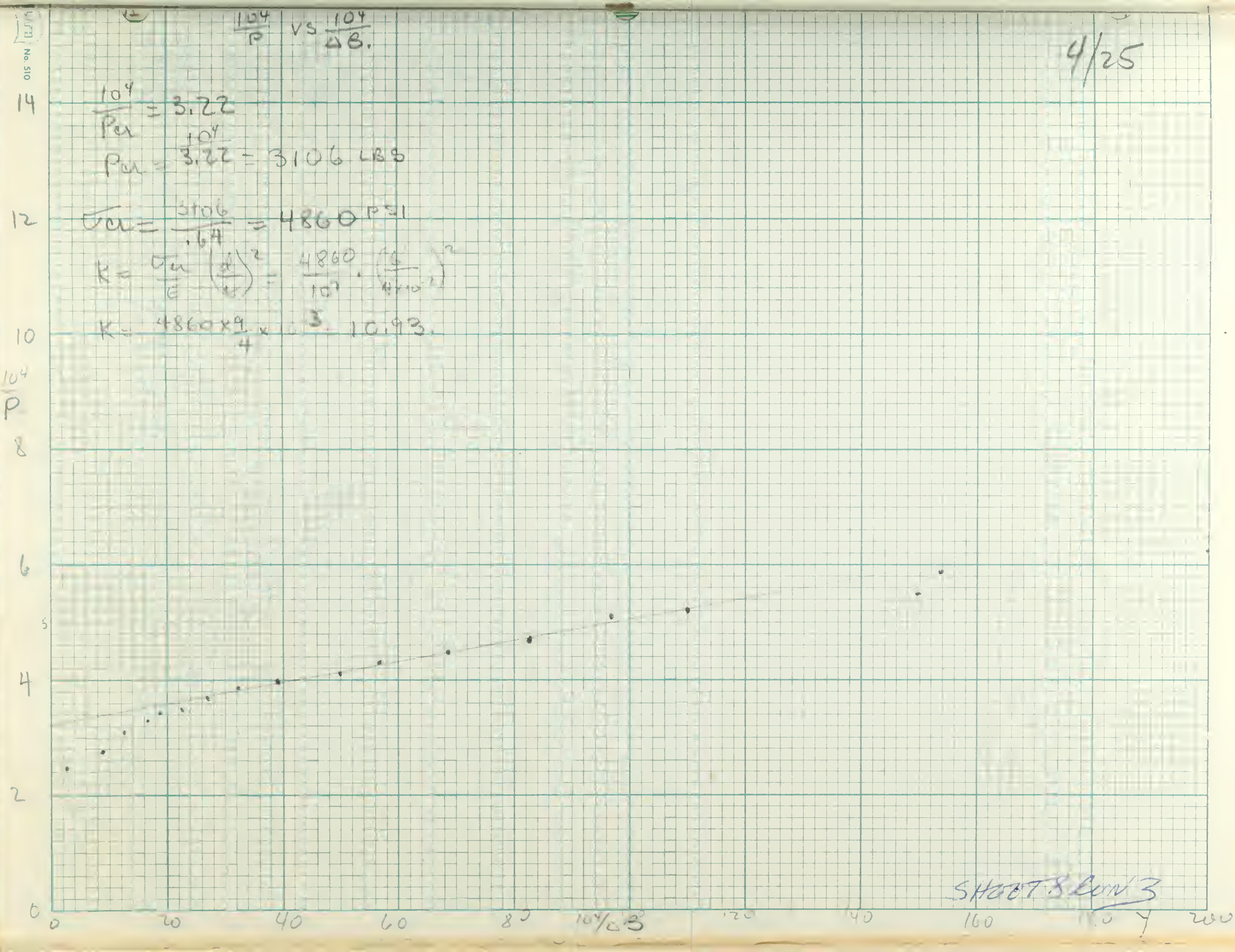
$\frac{10^4}{P_{cr}} = 3.22$

$P_{cr} = \frac{10^4}{3.22} = 3106$ LBS

$\sigma_{cr} = \frac{3106}{.64} = 4860$ PSI

$K = \frac{\sigma_{cr}}{E}\left(\frac{l}{r}\right)^2 = \frac{4860}{10^7} \cdot \left(\frac{[illegible]}{4\times10^{[illegible]}}\right)^2$

$K = \frac{4860\times9}{4} \times [illegible]\,3 = 10.93.$



4/25

$\frac{\Delta B}{P}$ vs ΔB

$$P_{cr} = \frac{\delta \Delta B}{\delta \frac{\Delta B}{P}} = \frac{800-200}{3590-880} = \frac{600}{1710} = 3510 \text{ LBS}$$

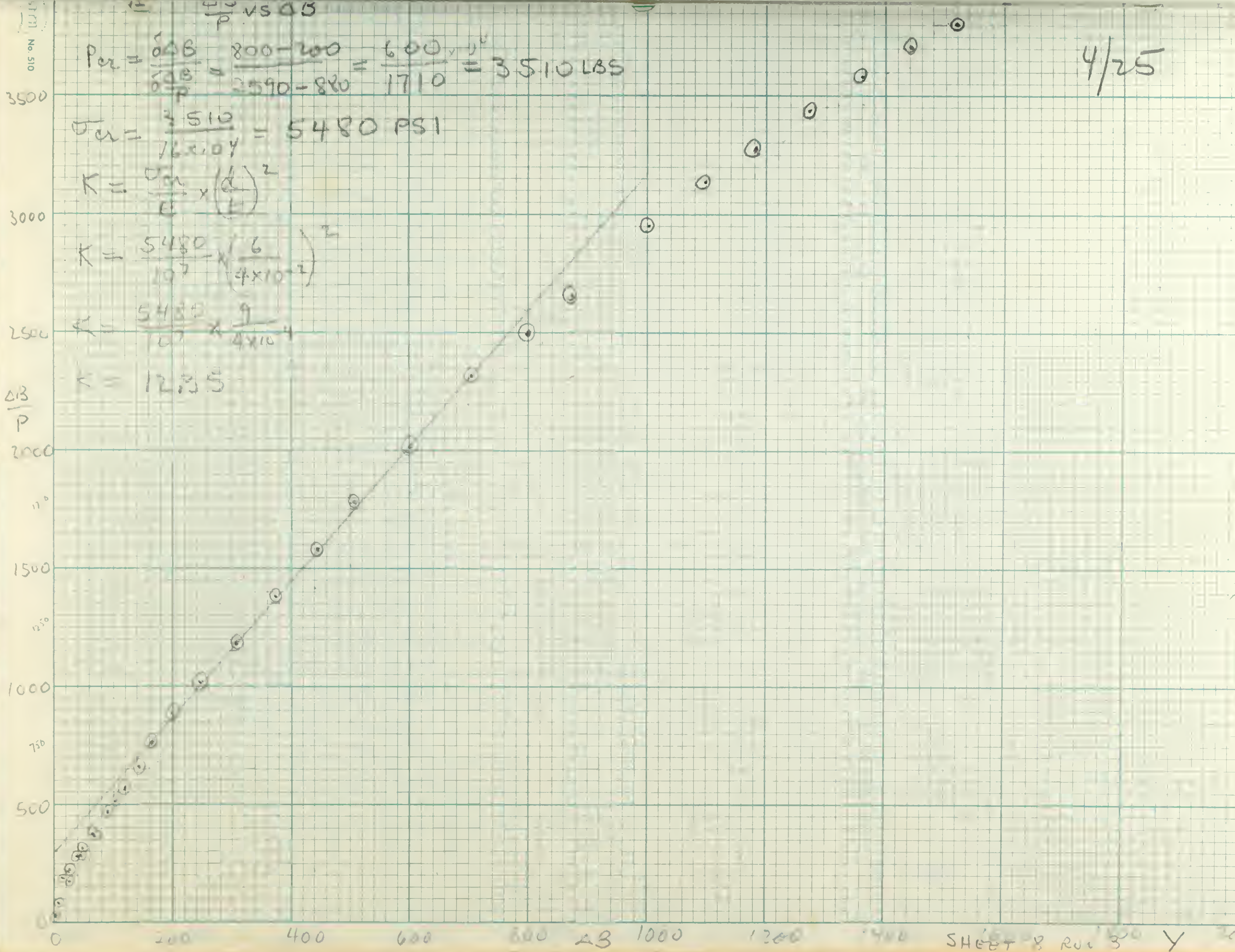
$$\sigma_{cr} = \frac{3510}{.64 \times 10^{?}} = 5480 \text{ PSI}$$

$$K = \frac{\sigma_{cr}}{E} \times \left(\frac{d}{t}\right)^2$$

$$K = \frac{5480}{10^7} \times \left(\frac{6}{4\times10^{-2}}\right)^2$$

$$K = \frac{5480}{10^7} \times \frac{9}{4\times10^{-4}}$$

$$K = 1235$$



RUN 1

LOAD P	$\frac{10^4}{P}$	B	ΔB	$\frac{10^4}{\Delta B}$	$\frac{\Delta B}{P} \times 10^4$	T	ΔT	STR
0		1348	0					
100	100	1348	0					
200	50	1339	9		450			
300	33.3	1345	3	3333	100			
400	25	1343	5	2000	125			
[illegible]	20	1343	5	2000	100			
[illegible]	16.7	1338	10	1000	167			
700	14.3	1335	13	769	186			
800	12.5	1333	15	667	188			
900	11.1	1328	20	500	222			
1000	10.0	1329	19	526	190			
1100	9.09	1322	26	384	236			
1200	8.33	1322	26	384	217			
1300	7.69	1322	26	384	200			
1400	7.14	1318	30	333	214			
1500	6.67	1312	36	277	240			
1600	6.24	1309	39	256	244			
[illegible]	5.88	1309	39	256	229			
1800	5.56	1304	44	227	244			
1900	5.26	1300	48	208	253			
[illegible]	5.00	1294	54	185	270			
2100	4.76	1289	59	169	281			
[illegible]	4.54	1284	64	156	291			
[illegible]	4.35	1281	67	149	291			
[illegible]	4.16	1273	75	133	313			

LOAD P	$\frac{10^4}{P}$	B	ΔB	$\frac{10^4}{\Delta B}$	$\frac{\Delta B}{P} \times 10^4$	T	T
2500	4.00	1272	76	132	304		
2600	3.84	1263	85	118	327		
2700	3.70	1256	92	109	341		
2800	3.57	1248	100	100	357		
2900	3.45	1235	113	88.5	390		
3000	3.33	1219	129	77.5	430		
3200	3.13	1186	162	61.7	506		
3400	2.94	1138	210	47.6	618		
3600	2.78	1064	284	35.2	789		
3800	2.63	945	403	24.8	1060		
4000	2.50	788	660	15.2	1650		

RP-450

SHEET 9 RUN 1

R

SHEET 9 RUN 1 16 X 36 X .040 24ST6-T3 ALUM WITH 5.5" HOLE. 3/26/57 DAVIS

PLOT OF $\frac{\Delta B}{P} \times 10^4$ VS ΔB TO DETERMINE P_{cr} BY SLOPE

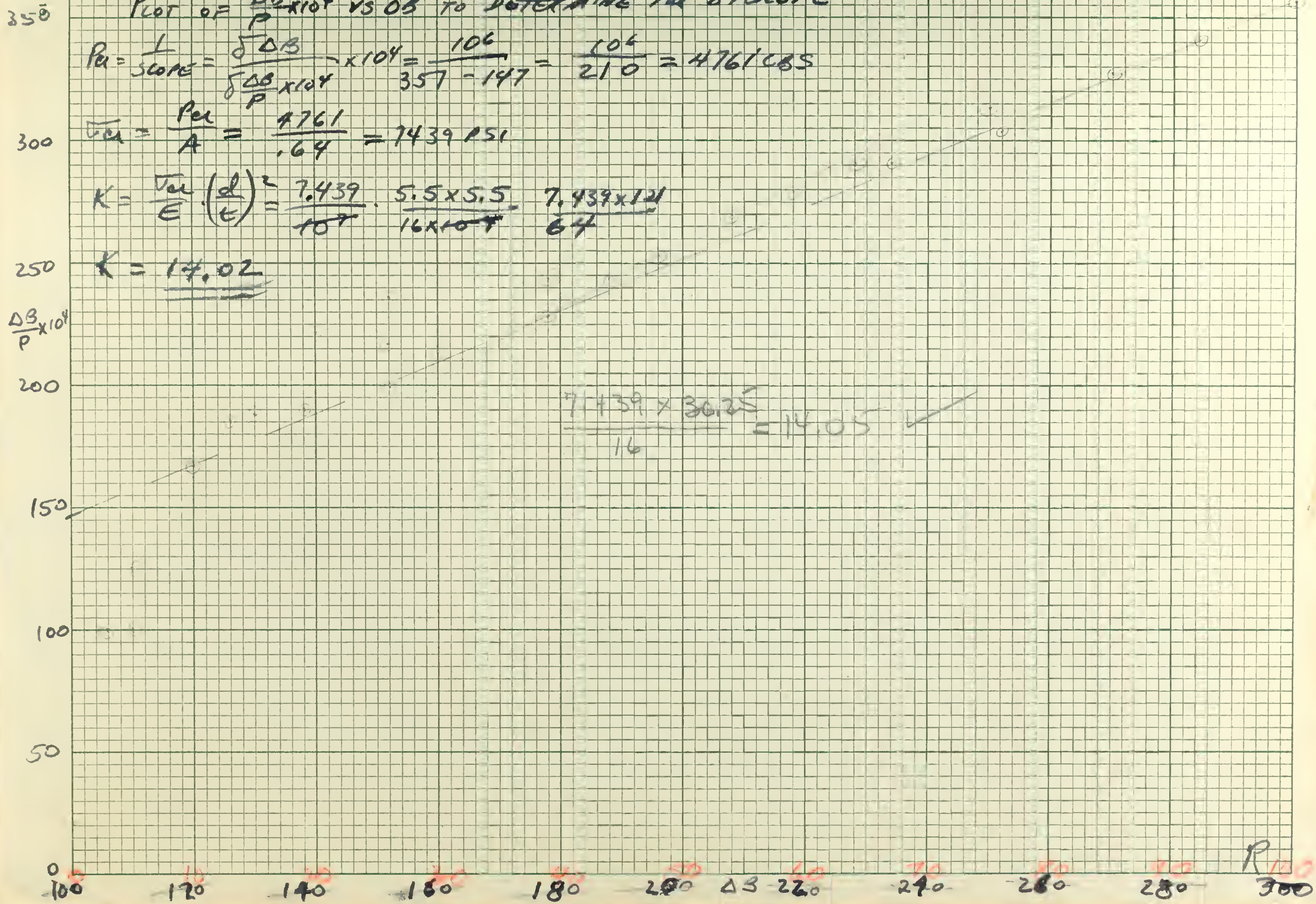
$$P_{cr} = \frac{1}{SLOPE} = \frac{\delta \Delta B}{\delta \frac{\Delta B}{P} \times 10^4} \times 10^4 = \frac{10^6}{357 - 147} = \frac{10^6}{210} = 4761 \text{ LBS}$$

$$\sigma_{cr} = \frac{P_{cr}}{A} = \frac{4761}{.64} = 7439 \text{ PSI}$$

$$K = \frac{\sigma_{cr}}{E} \left(\frac{d}{t}\right)^2 = \frac{7.439}{\cancel{10^4}} \cdot \frac{5.5 \times 5.5}{16 \times \cancel{10^{-4}}} = \frac{7.439 \times 121}{64}$$

$$\underline{\underline{K = 14.02}}$$

$$\frac{7.439 \times 30.25}{16} = 14.05$$



$\frac{1}{P}$ vs $\frac{10^4}{\Delta B}$

$P_{cr} = \frac{10^4}{2.29} = 4367$

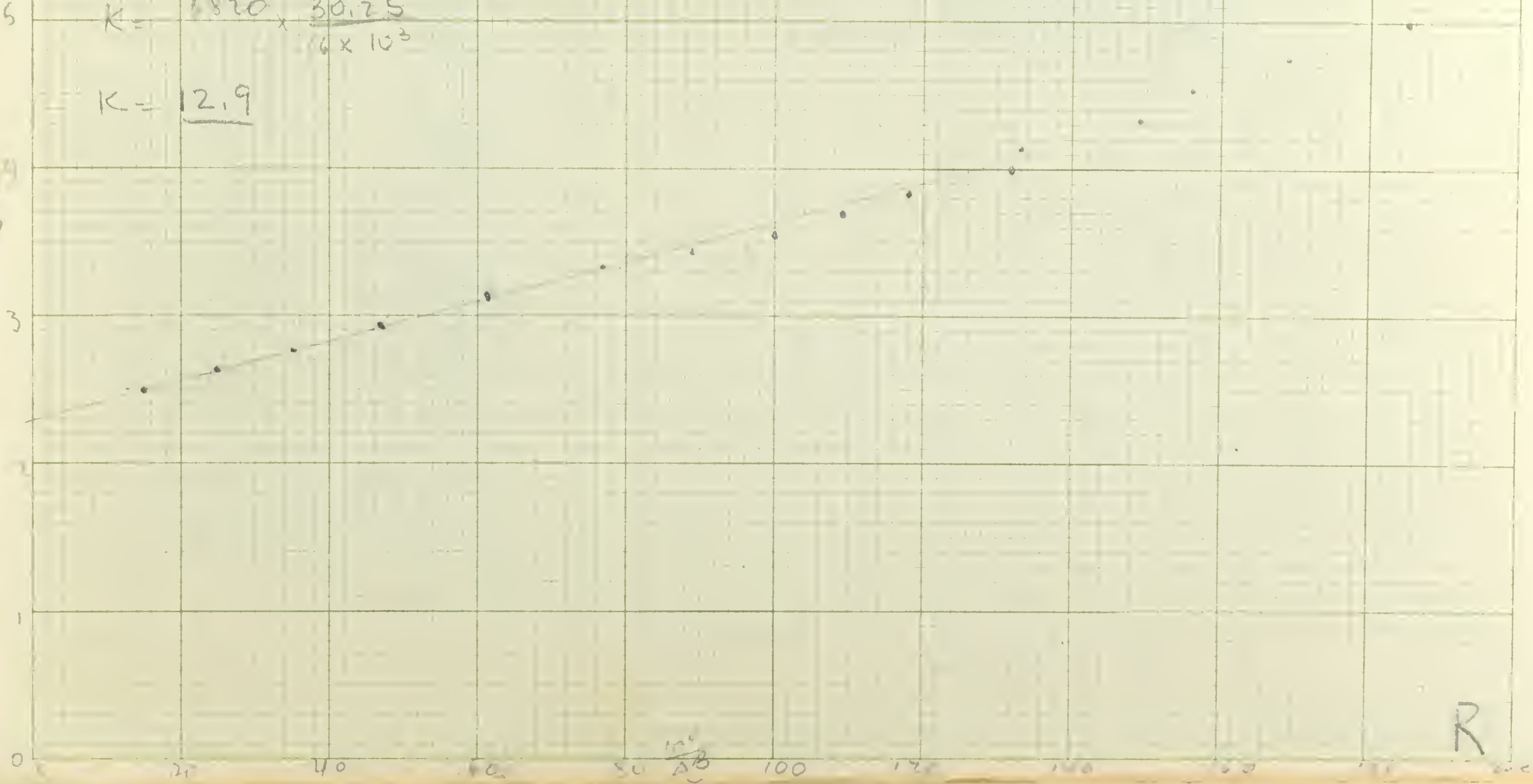
$\sigma_{cr} = \frac{4367}{.64} = 6820$

$K = \frac{\sigma_{cr}}{E} \cdot \left(\frac{d}{t}\right)^2$

$K = \frac{6820}{10^7} \times \left(\frac{5.5}{4\times10^{-2}}\right)^2$

$K = \frac{6820}{} \times \frac{30.25}{16\times10^3}$

$K = \underline{12.9}$



J H WEIL & CO. PHILA 10 X 10 TO 1 INCH

LOAD P	$\frac{10^4}{P}$	B	ΔB	$\frac{10^4}{\Delta B}$	$\frac{\Delta B}{P} \times 10^4$	T	ΔT	STRESS
0		1360	0	—				
100	100	1345	15		1500			
200	50	1341	19		950			
300	33.3	1341	19		633			
400	25	1343	17		425			
500	20	1340	20		400			
600	16.7	1338	22		367			
700	14.3	1334	26		371			
800	12.5	1335	25		313			
900	11.1	1331	29		322			
1000	10.0	1330	30		300			
1100	9.09	1328	32		291			
1200	8.33	1325	35		291			
1300	7.69	1322	38		292			
1400	7.14	1319	41	244	293			
1500	6.67	1318	42	238	280			
1600	6.24	1310	50	200	313			
1700	5.88	1309	51	196	300			
1800	5.56	1301	59	169	328			
1900	5.26	1300	60	167	316			
2000	5.00	1299	61	164	305			
2100	4.76	1292	68	147	324			
2200	4.54	1289	71	141	323			
2300	4.35	1282	78	128	339			
2400	4.16	1278	82	122	342			

LOAD P	$\frac{10^4}{P}$	B	ΔB	$\frac{10^4}{\Delta B}$	$\frac{\Delta B}{P} \times 10^4$	T	ΔT	STRESS
2500	4.00	1270	90	111	360			
2600	3.84	1261	99	101	381			
2700	3.70	1252	108	92.6	400			
2800	3.57	1242	118	84.7	421			
2900	3.45	1238	122	81.9	421			
3000	3.33	1220	140	71.4	467			
3200	3.13	1194	166	60.2	518			
3400	2.94	1140	220	45.5	647			
3600	2.78	1062	298	33.6	828			
3800	2.63	944	416	24.0	1095			
4000	2.50	782	578	17.3	1445			

RP-450

SHEET 9 RUN 2

S

SHEET 9 RUN 2 16 x 36 x .040" 2024-T3 ALUM WITH 5.5" HOLE 3/26/57 DAVIS

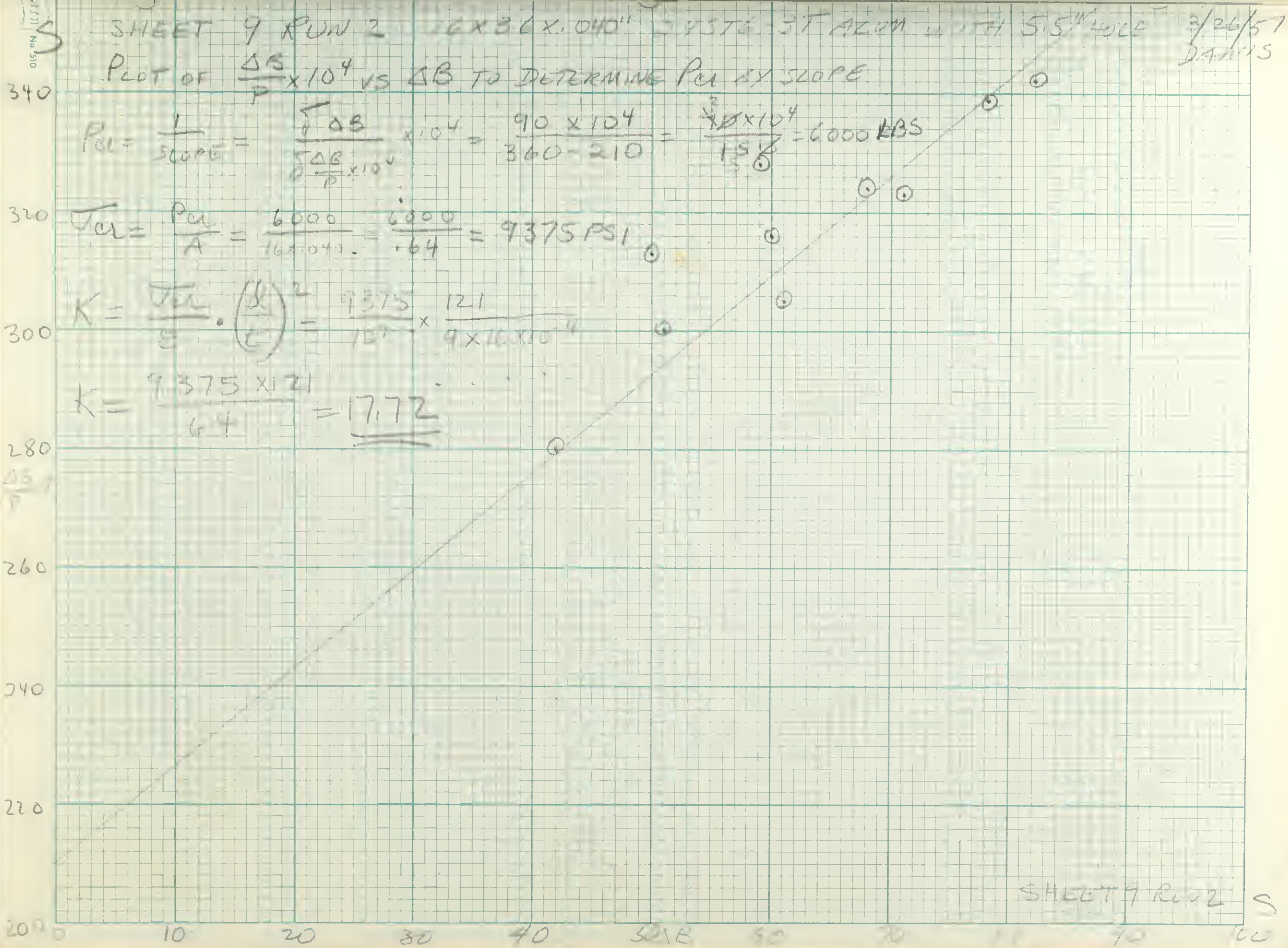
PLOT OF $\frac{\Delta B}{P} \times 10^4$ VS ΔB TO DETERMINE P_{cr} BY SLOPE

$$P_{cr} = \frac{1}{\text{SLOPE}} = \frac{\int \Delta B}{\int \frac{\Delta B}{P} \times 10^4} \times 10^4 = \frac{90 \times 10^4}{360 - 210} = \frac{\cancel{90} \times 10^4}{\cancel{150}} = 6000 \text{ LBS}$$

$$\sigma_{cr} = \frac{P_{cr}}{A} = \frac{6000}{16 \times .040} = \frac{6000}{.64} = 9375 \text{ PSI}$$

$$K = \frac{\sigma_{cr}}{E} \cdot \left(\frac{b}{t}\right)^2 = \frac{9375}{10^7} \times \frac{121}{4 \times 16 \times 10^{-4}}$$

$$K = \frac{9375 \times 121}{64} = 17.72$$



SHEET 9 RUN 2 16x36x.040" WITH 5.5" HOLE. 3/26

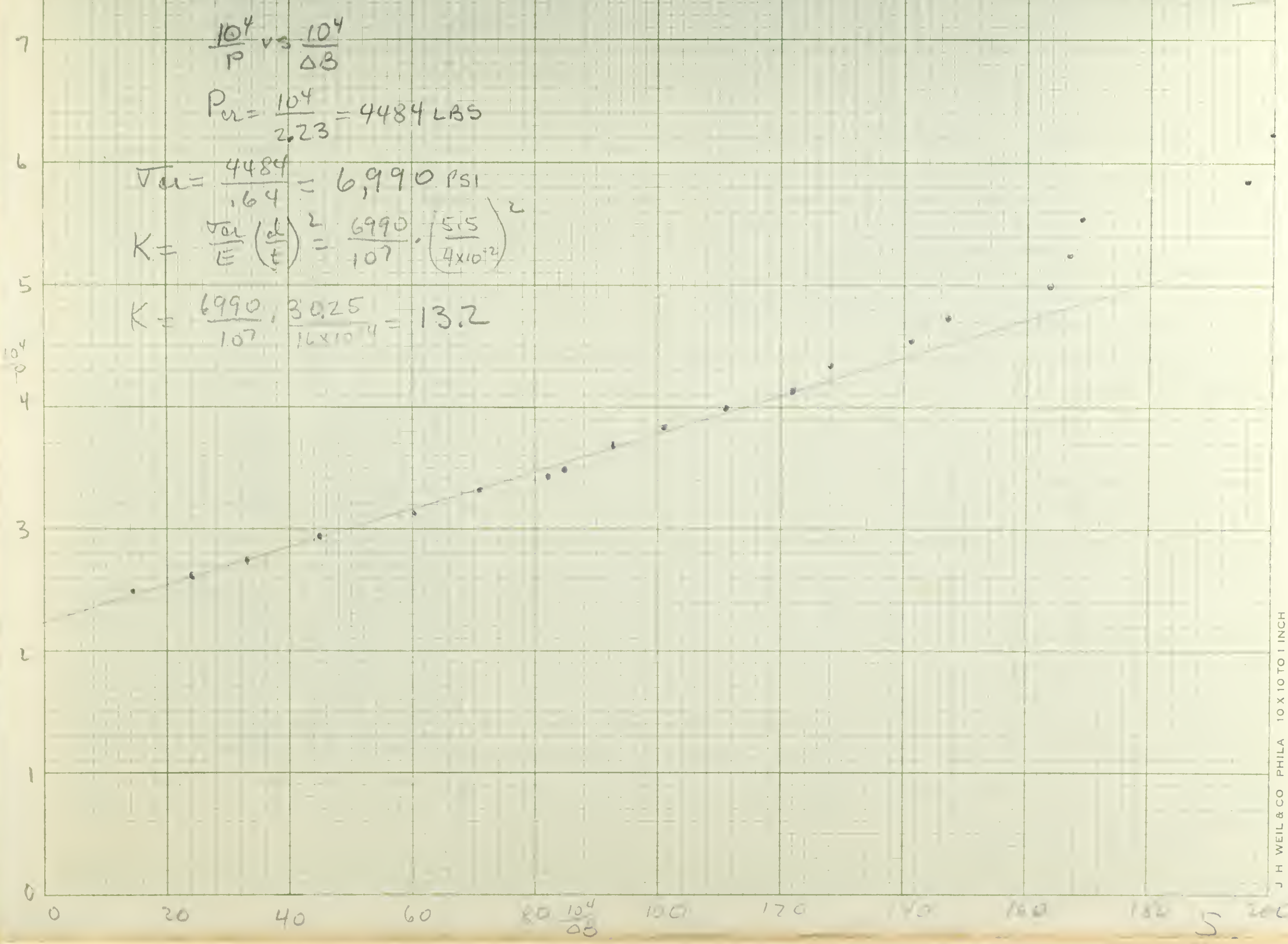
$\frac{10^4}{P}$ vs $\frac{10^4}{\Delta B}$

$P_{cr} = \frac{10^4}{2.23} = 4484$ LBS

$\sigma_{cr} = \frac{4484}{.64} = 6,990$ PSI

$K = \frac{\sigma_{cr}}{E}\left(\frac{d}{t}\right)^2 = \frac{6990}{10^7} \cdot \left(\frac{5.5}{4 \times 10^{-2}}\right)^2$

$K = \frac{6990}{10^7} \cdot \frac{30.25}{16 \times 10^{-4}} = 13.2$



5

P	$\frac{10^4}{P}$	B	ΔB	$\frac{10^4}{\Delta B}$	$\frac{\Delta B}{P} \times 10^4$	T	ΔT	STRESS
0		1362	—					
100	100	1350	12		1200			
200	50	1352	10		500			
300	33.3	1342	20		667			
400	25	1350	12		300			
500	20	1339	23		460			
600	16.7	1336	26		433			
700	14.3	1338	24		343			
800	12.5	1337	25		313			
900	11.1	1332	30		333			
1000	10.0	1330	32		320			
1100	9.09	1328	34		309			
1200	8.33	1322	40		333			
1300	7.69	1320	42	238	323			
1400	7.14	1322	40	250	286			
1500	6.67	1318	44	227	293			
1600	6.24	1315	47	213	294			
1700	5.88	1310	52	192	306			
1800	5.56	1304	58	172	322			
1900	5.26	1301	61	164	321			
2000	5.00	1300	62	161	310			
2100	4.76	1298	64	156	305			
2200	4.54	1291	71	141	323			
2300	4.35	1283	79	127	343			
2400	4.16	1280	82	122	342			

P	$\frac{10^4}{P}$	B	ΔB	$\frac{10^4}{\Delta B}$	$\frac{\Delta B}{P} \times 10^4$	T	ΔT	STRESS
2500	4.00	1270	92	109	368			
2600	3.84	1268	94	106	362			
2700	3.70	1255	107	93.5	396			
2800	3.57	1250	112	89.3	400			
2900	3.45	1232	130	76.9	448			
3000	3.33	1225	137	73.0	457			
3200	3.13	1194	168	59.5	525			
3400	2.94	1140	222	45.0	653			
3600	2.78	1068	294	34.0	817			
3800	2.63	942	420	23.8	1105			
4000	2.50	782	580	17.2	1450			

SHEET 9 RUN 3

RP-450

T

$\frac{10^4}{P}$ vs $\frac{10^4}{\Delta\theta}$

$\frac{10^4}{P_{cr}} = 2.23$

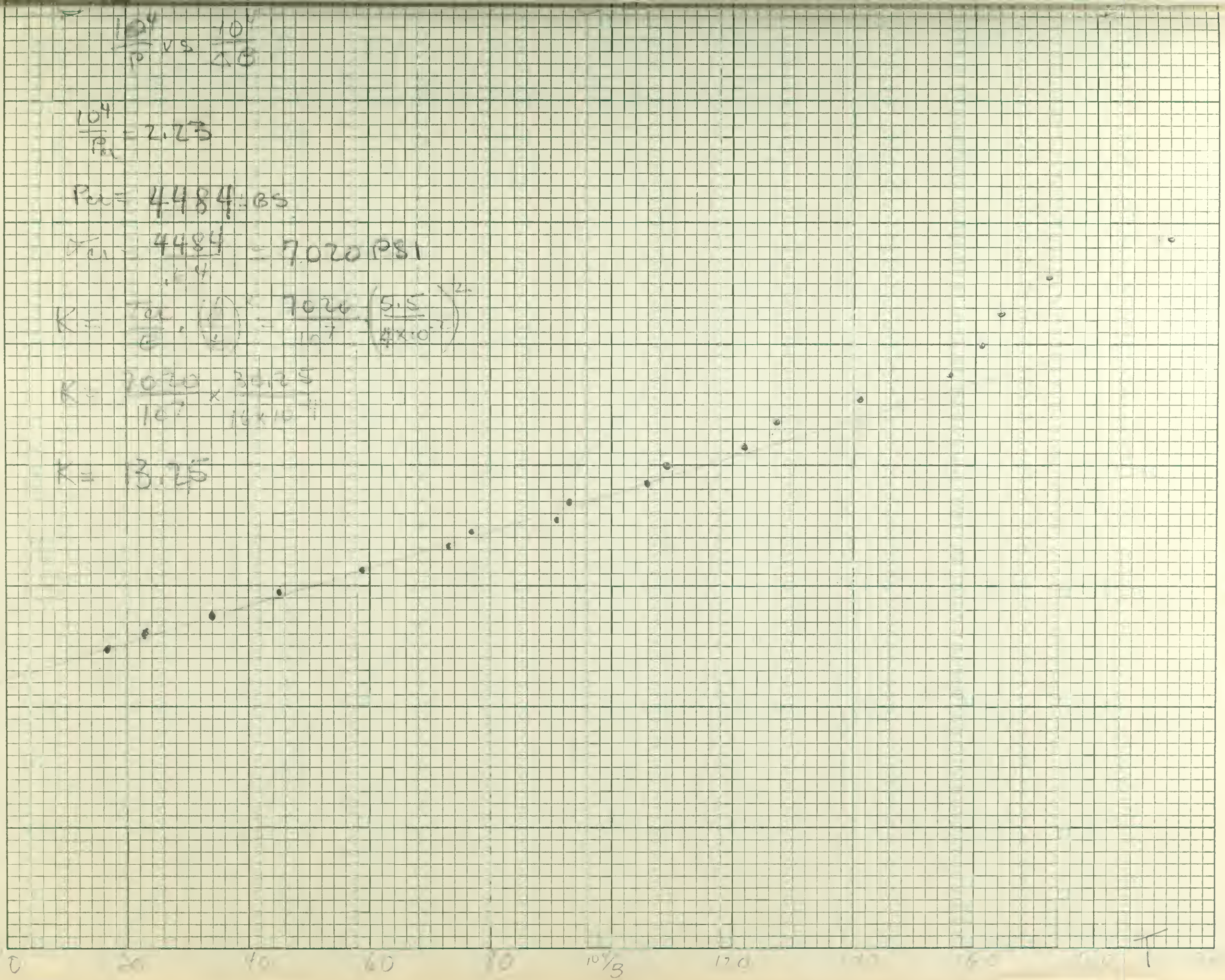
$P_{cr} = 4484.85$

$\sigma_{cr} = \frac{4484}{.64} = 7020$ PSI

$K = \frac{\sigma_{cr}}{E} \cdot \left(\frac{l}{t}\right)^2 = \frac{7020}{10^7} \left(\frac{5.5}{4 \times 10^{-2}}\right)^2$

$K = \frac{7020}{10^7} \times \frac{30.25}{16 \times 10^{-4}}$

$K = 13.25$



BEE 10 x 10

SHEET 9 RUN 3 16 x 36 x .040" 24ST6-T3 ALUM WITH 5.5" HOLE 3/26/57

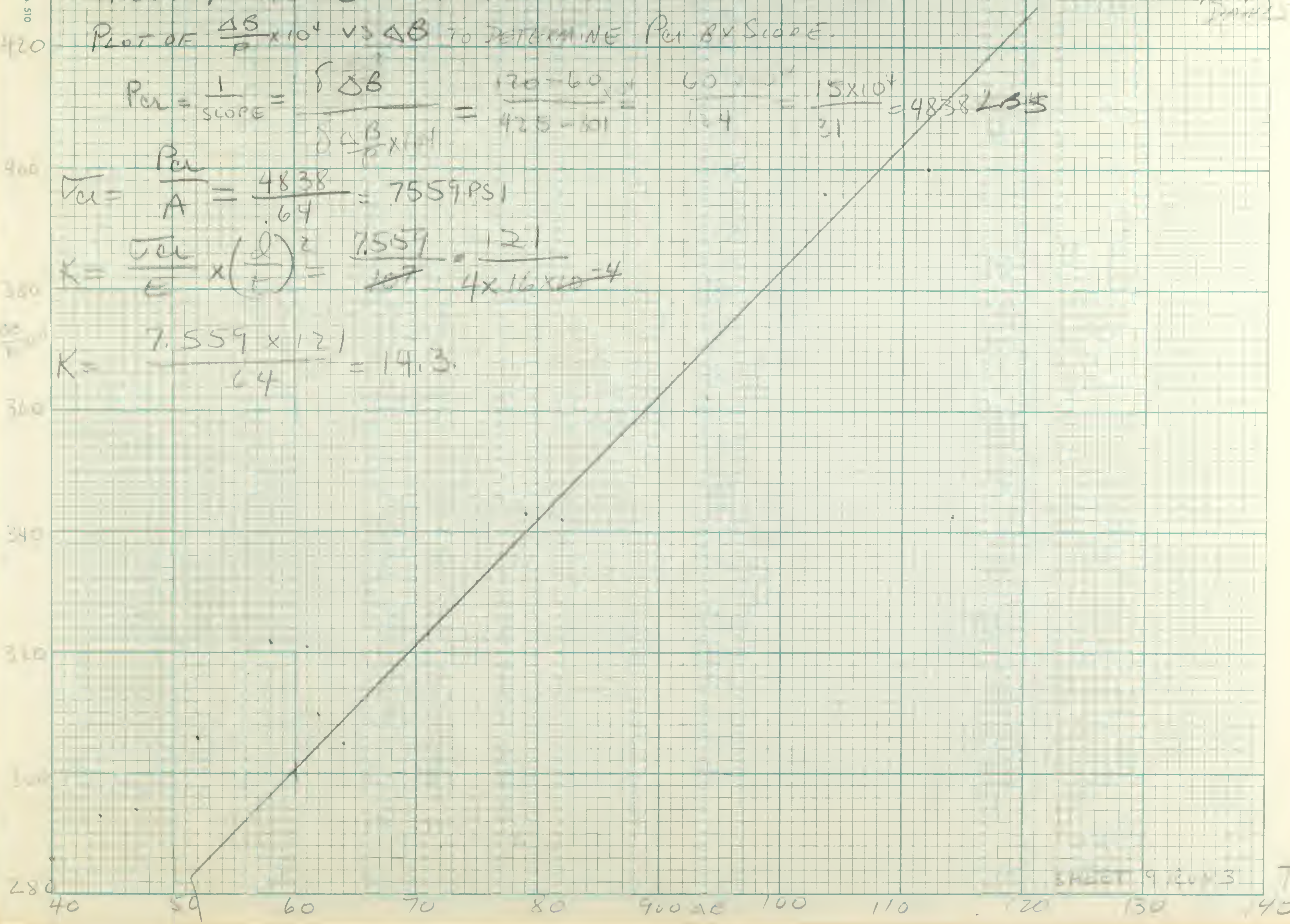
PLOT OF $\frac{\Delta\delta}{P} \times 10^4$ VS $\Delta\delta$ TO DETERMINE P_{cr} BY SLOPE.

$$P_{cr} = \frac{1}{\text{SLOPE}} = \frac{\delta\,\Delta\delta}{\delta\,\frac{\Delta\delta}{P}\times 10^4} = \frac{120-60}{425-301}\times 10^4 = \frac{60}{124} = \frac{15\times 10^4}{31} = 4838\ \text{LBS}$$

$$\sigma_{cr} = \frac{P_{cr}}{A} = \frac{4838}{.64} = 7559\ \text{PSI}$$

$$K = \frac{\sigma_{cr}}{E}\times\left(\frac{l}{t}\right)^2 = \frac{7559}{\cancel{10^7}}\cdot\frac{121}{4\times 16\times \cancel{10^{-4}}}$$

$$K = \frac{7.559\times 121}{64} = 14.3$$



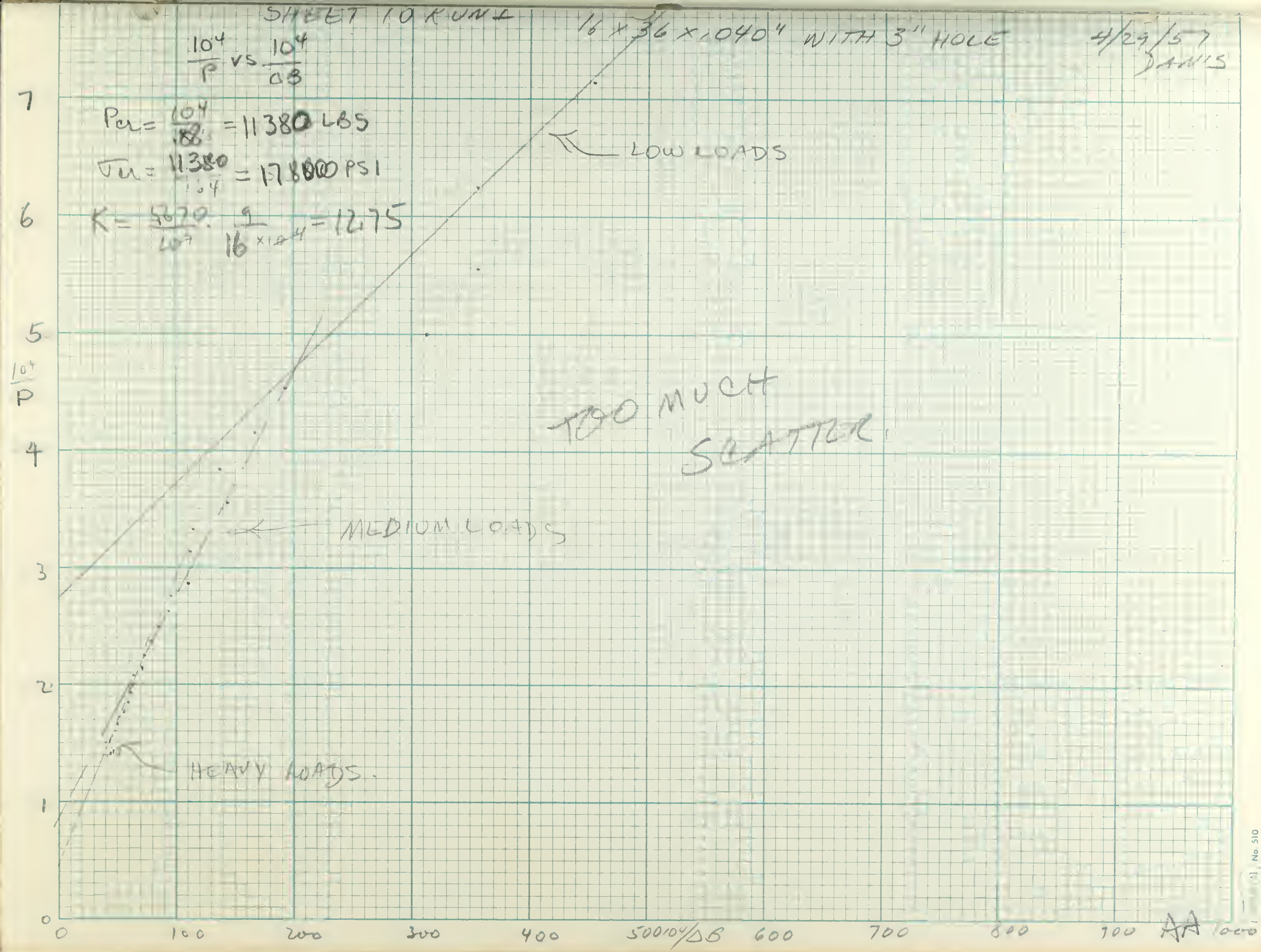
S

P	$10^4/P$	B	ΔB	ΔB/P	$10^4/\Delta B$
0					
100					
200					
300					
[illegible]					
[illegible]					
[illegible]					
700					
800					
900					
[illegible]					
[illegible]					
[illegible]					
0		630	0		—
100	100	638	−8		
200	50	638	−8		
300	33.3	631	−1		
400	25	630	0		—
600	16.7	628	2	33.3	5000
800	12.5	625	5	62.5	2000
1000	10.0	620	10	100	1000
1200	8.33	612	18	150	556
1400	7.14	608	22	157	455
1600	6.24	602	28	175	357
1800	5.56	602	28	156	357
2000	5	598	32	160	313

P	$10^4/P$	B	ΔB	ΔB/P	$10^4/\Delta B$
2200	4.54	578	52	236	192
2400	4.16	570	60	250	167
2600	3.84	558	72	277	139
2800	3.57	560	70	250	143
3000	3.33	543	87	290	115
3200	3.13	541	89	278.1	112
3400	2.94	532	98	288.2	102
3600	2.78	525	105	291	15.2
3800	2.63	523	107	281	93.4
4000	2.50	512	118	295	84.7
4200	2.38	502	128	304	78.1
4400	2.27	494	136	309	73.5
4600	2.17	488	142	308	70.4
4800	2.08	475	155	322	64.5
5000	2.00	474	156	312	64.1
5200	1.92	468	162	311	61.7
5400	1.85	462	168	311	59.5
5600	1.78	449	181	323	55.2
5800	1.72	439	191	329	52.4
6000	1.67	436	194	323	51.5
6200	1.61	428	202	325	49.5
6400	1.56	421	209	326	47.8
6600	1.51	409	221	334	45.2
6800	1.47	392	238	350	42.0
6400	1.45	391	239	346	41.8
7000	1.43	390	240	342	41.6

RP-450

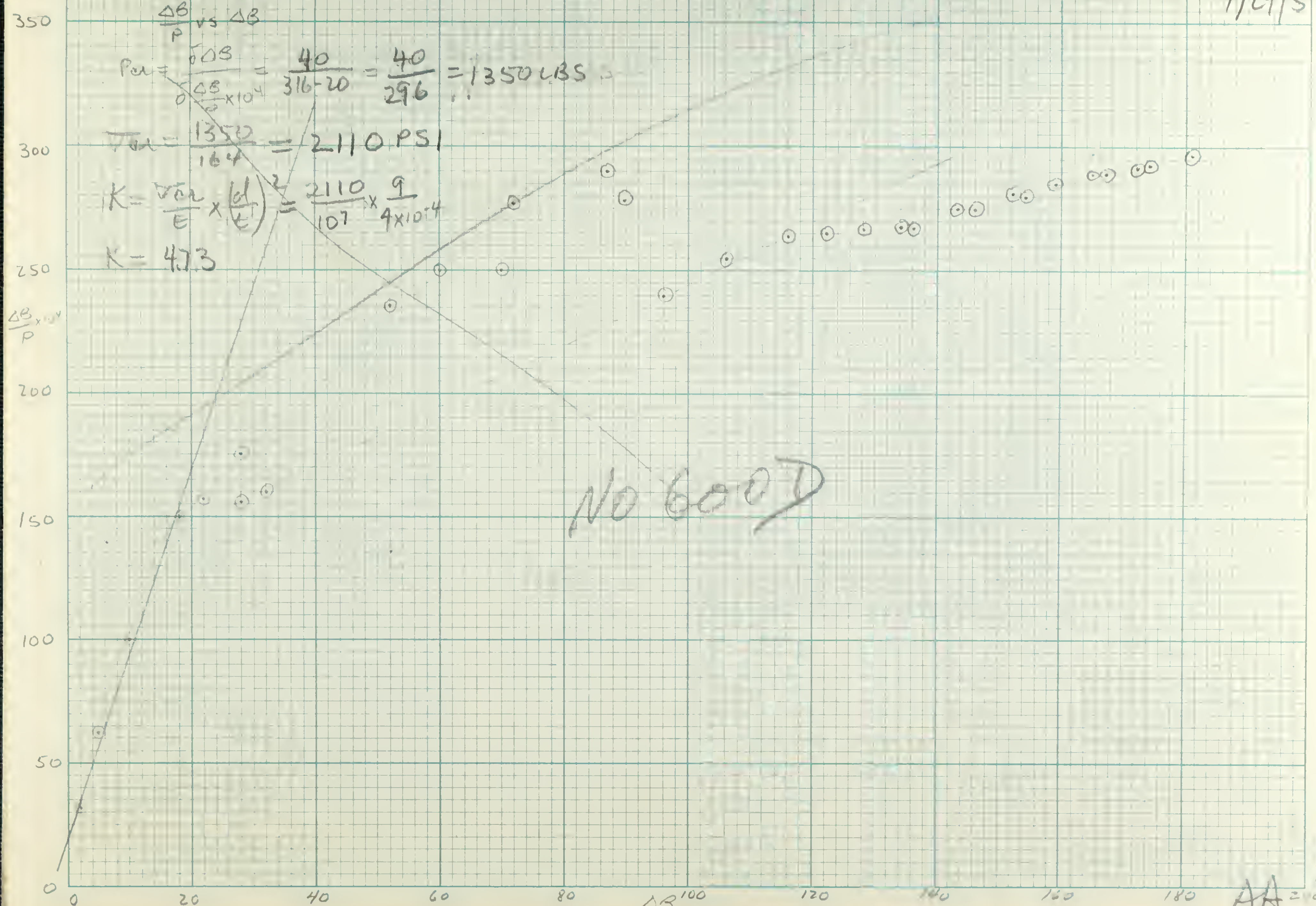
AA.



SHEET 10 KRUNA
1/16 × 36 × .040" WITH 3" HOLE
4/29/57
DAVIS
$\frac{10^4}{P}$ vs $\frac{10^4}{\Delta\delta}$
$P_{cr} = \frac{10^4}{.88} = 11380$ LBS
$\sigma_{cr} = \frac{11380}{.64} = 17800$ PSI
$K = \frac{5070}{10^4} \cdot \frac{9}{16 \times 10^{-4}} = 12.75$
LOW LOADS
MEDIUM LOADS
HEAVY LOADS.
TOO MUCH SCATTER
$\frac{10^4}{P}$
0
1
2
3
4
5
6
7
0
100
200
300
400
500 $10^4/\Delta\delta$
600
700
800
900
1000
AA
No. 510

SHEET 10 RUN 1 24S-T3 ALUMINUM 16X36X.040" WITH 3" HOLE.

4/29/51



$$P_{cr} = \frac{\delta \Delta B}{\delta \frac{\Delta B}{P} \times 10^4} = \frac{40}{316-20} = \frac{40}{296} = 1350 \text{ LBS}$$

$$\sigma_{cr} = \frac{1350}{.64} = 2110 \text{ PSI}$$

$$K = \frac{\sigma_{cr}}{E} \times \left(\frac{d}{t}\right)^2 = \frac{2110}{10^7} \times \frac{9}{4 \times 10^{-4}}$$

$$K = 4.73$$

P	$\frac{10^4}{P}$	B	ΔB	$\frac{\Delta B}{P}\times 10^4$	$\frac{10^4}{\Delta B}$
0	— ↓	634			↓
[illegible]	100	637			
[illegible]	50	635			
[illegible]	33.3	632	2	6.67	5000
[illegible]	25	632	2	50	5000
600	16.7	628	6	100	1666
[illegible]	12.5	625	9	113	1111
1000	10	621	13	130	769
1200	8.33	615	19	158	526
1400	7.14	610	24	171	417
1600	6.24	605	29	181	345
1800	5.56	[illegible]	34	189	294
2000	5.00	594	40	200	250
[illegible]	4.54	590	44	200	227
[illegible]	4.16	582	52	217	192
[illegible]	3.86	578	56	215	179
[illegible]	3.57	570	64	229	156
[illegible]	3.33	568	66	220	152
[illegible]	3.13	561	73	228	137
[illegible]	2.94	555	79	232	127
[illegible]	2.78	548	86	239	116
[illegible]	2.63	543	91	239	110
[illegible]	2.50	538	96	240	104
4200	2.38	528	106	252	94.3
[illegible]	2.27	518	116	264	86.2
[illegible]	2.17	512	122	265	82.0
[illegible]	2.08	506	128	267	78.1

P	$\frac{10^4}{P}$	B	ΔB	$10^4/\Delta B$	$\frac{\Delta B}{P}\times 10^4$
5000	2.00	500	134	74.6	268
5100	1.96	498	136	73.5	267
5200	1.92	491	143	69.9	275
5300	1.89	488	146	68.5	275
5400	1.85	482	152	65.8	281
5500	1.82	480	154	64.9	280
[illegible]	1.78	475	159	62.9	284
[illegible]	1.75	469	165	60.6	289
[illegible]	1.72	467	167	59.9	288
[illegible]	1.69	462	172	58.1	292
6000	1.67	458	176	56.8	293
6100	1.63	453	181	55.2	297
6200	1.61	451	183	54.6	295
[illegible]	1.59	448	186	53.8	295
[illegible]	1.56	441	193	51.8	302
[illegible]	1.54	438	196	51.0	302
[illegible]	1.51	434	200	50.0	303
[illegible]	1.49	431	203	49.2	302
[illegible]	1.47	423	211	47.4	310
[illegible]	1.45	418	216	46.3	313
7000	1.43	411	223	44.8	319

BB

$\frac{10^4}{P}$ vs $\frac{10^4}{\Delta B}$

$\cancel{P_{cr} = \frac{10^4}{4.65} = 2150 \text{ LBS}}$

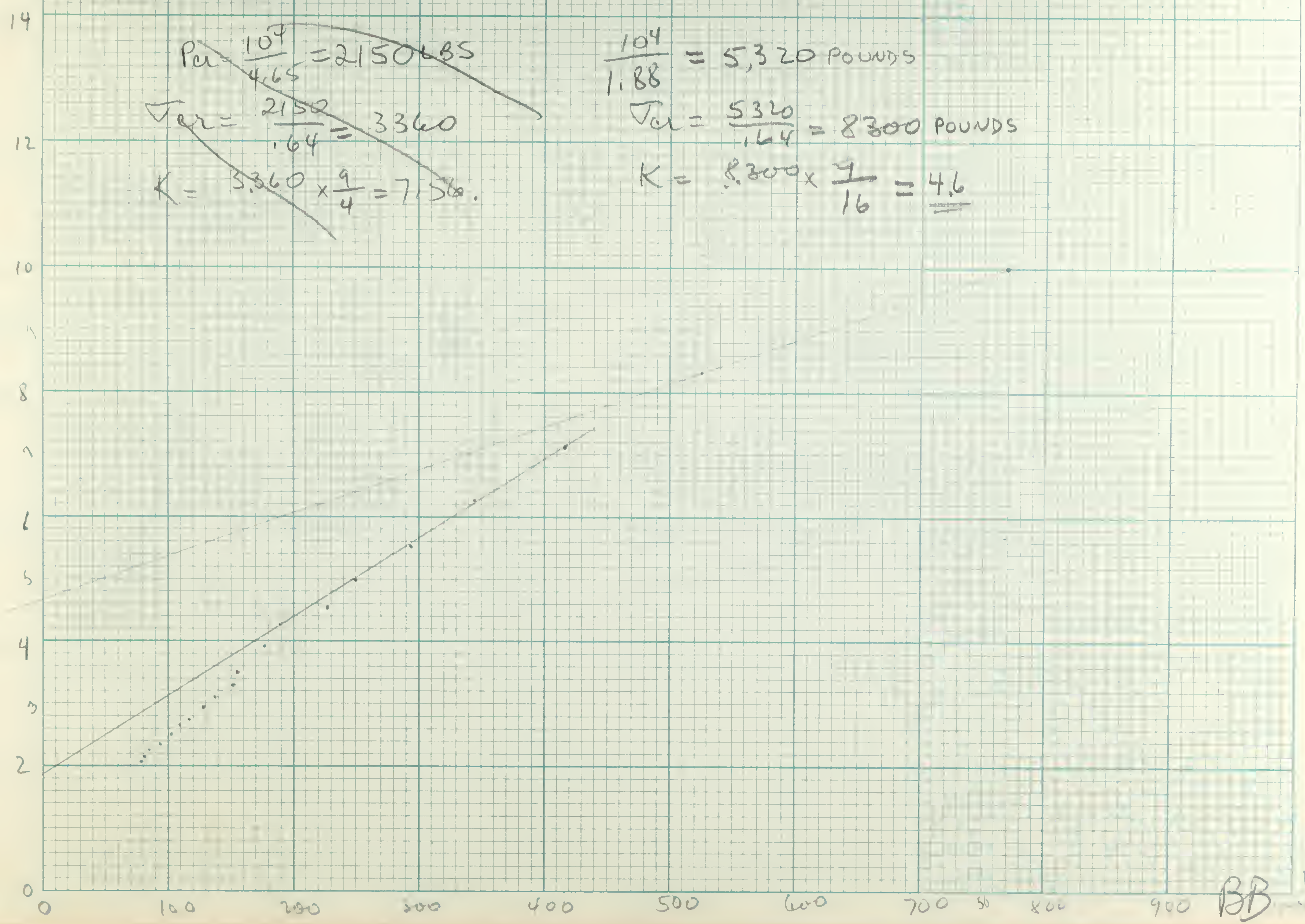
$\cancel{\sigma_{cr} = \frac{2150}{.64} = 3360}$

$\cancel{K = 3360 \times \frac{9}{4} = 7560.}$

$\frac{10^4}{1.88} = 5{,}320$ POUNDS

$\sigma_{cr} = \frac{5320}{.64} = 8300$ POUNDS

$K = 8300 \times \frac{7}{16} = \underline{4.6}$



BB

No. 510

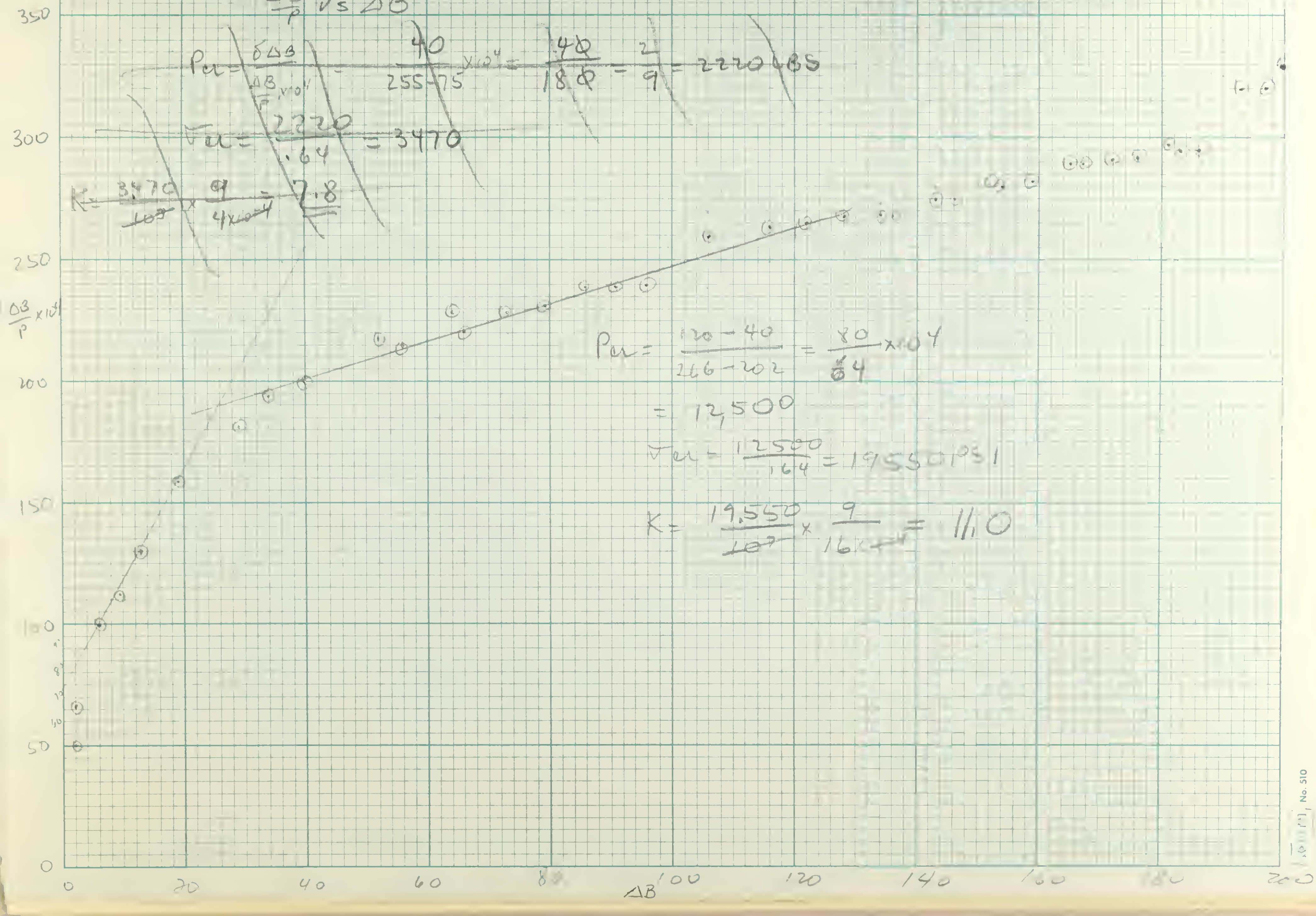
SHEET 10 RUN 2 24S-T3 ALUM WITH 3" HOLE 16 x 36 x .040" 5/6/57

$\frac{\Delta B}{P}$ vs ΔB

$$P_{cr} = \frac{\delta \Delta B}{\frac{\Delta B}{P} \times 10^{4}} = \frac{40}{255-75} \times 10^{4} = \frac{40}{180} = \frac{2}{9} = 2220 \text{ LBS}$$

$$\sigma_{cr} = \frac{2220}{.64} = 3470$$

$$K = \frac{3470}{10^7} \times \frac{9}{4 \times 10^{-4}} = 7.8$$



$$P_{cr} = \frac{120-40}{266-202} = \frac{80}{64} \times 10^{4} = 12{,}500$$

$$\sigma_{cr} = \frac{12500}{.64} = 19550 \text{ PSI}$$

$$K = \frac{19{,}550}{10^7} \times \frac{9}{16 \times 10^{-4}} = 11.0$$

SHEET 10 [illegible] 76x76x.040 [illegible] T3 ALUMINUM WITH 3" HOLE

P	$\frac{10^4}{P}$	B	ΔB	[illegible]	[illegible]				P	$10^4/P$	B	ΔB	[illegible]	[illegible]
0	—	701	—						5000	2	612	89	178	112
100	100	701	—						5100	1.96	611	90	176	111
200	50	702	—						5200	1.92	608	93	179	108
300	33.3	701	—						5300	1.89	604	92	174	109
400	25	701	—						5400	1.85	603	98	181	102
[illegible]	16.7	700	1		104				5500	1.82	602	99	180	101
[illegible]	12.5	700	1		104				5600	1.78	594	107	191	93.4
[illegible]	10	693	8	80	1250				[illegible]	1.75	600	101	177	99
[illegible]	8.33	[illegible]	14	117	714				[illegible]	1.72	596	105	181	95.2
[illegible]	7.14	[illegible]	19	136	526				5900	1.69	587	114	193	87.7
[illegible]	6.24	[illegible]	20	125	500				6000	1.67	587	114	190	87.8
[illegible]	5.56	678	23	128	435				[illegible]	1.63	582	119	195	84.0
[illegible]	5	676	25	125	400				[illegible]	1.61	582	119	192	84.0
[illegible]	4.54	672	29	132	345				[illegible]	1.59	573	128	203	78.1
[illegible]	4.16	665	36	150	278				[illegible]	1.56	[illegible]	130	203	76.9
[illegible]	3.86	662	39	150	256				[illegible]	1.54	568	133	204	75.1
[illegible]	3.57	655	46	164	217				[illegible]	1.51	[illegible]	138	209	72.5
[illegible]	3.33	[illegible]	49	163	233				[illegible]	1.49	561	140	209	71.4
[illegible]	3.13	[illegible]	51	159	196				[illegible]	1.47	[illegible]	143	210	69.9
[illegible]	2.94	648	53	156	188				[illegible]	1.45	558	143	207	69.9
[illegible]	2.78	[illegible]	59	164	169				[illegible]	1.43	554	147	210	68.0
[illegible]	2.63	642	59	155	169									
[illegible]	2.50	[illegible]	65	163	154									
[illegible]	2.38	[illegible]	65	155	154									
[illegible]	2.27	[illegible]	72	164	139									
[illegible]	2.17	620	81	176	123									
[illegible]	2.08	616	85	177	118									

SHEET 10 RUN 3CC

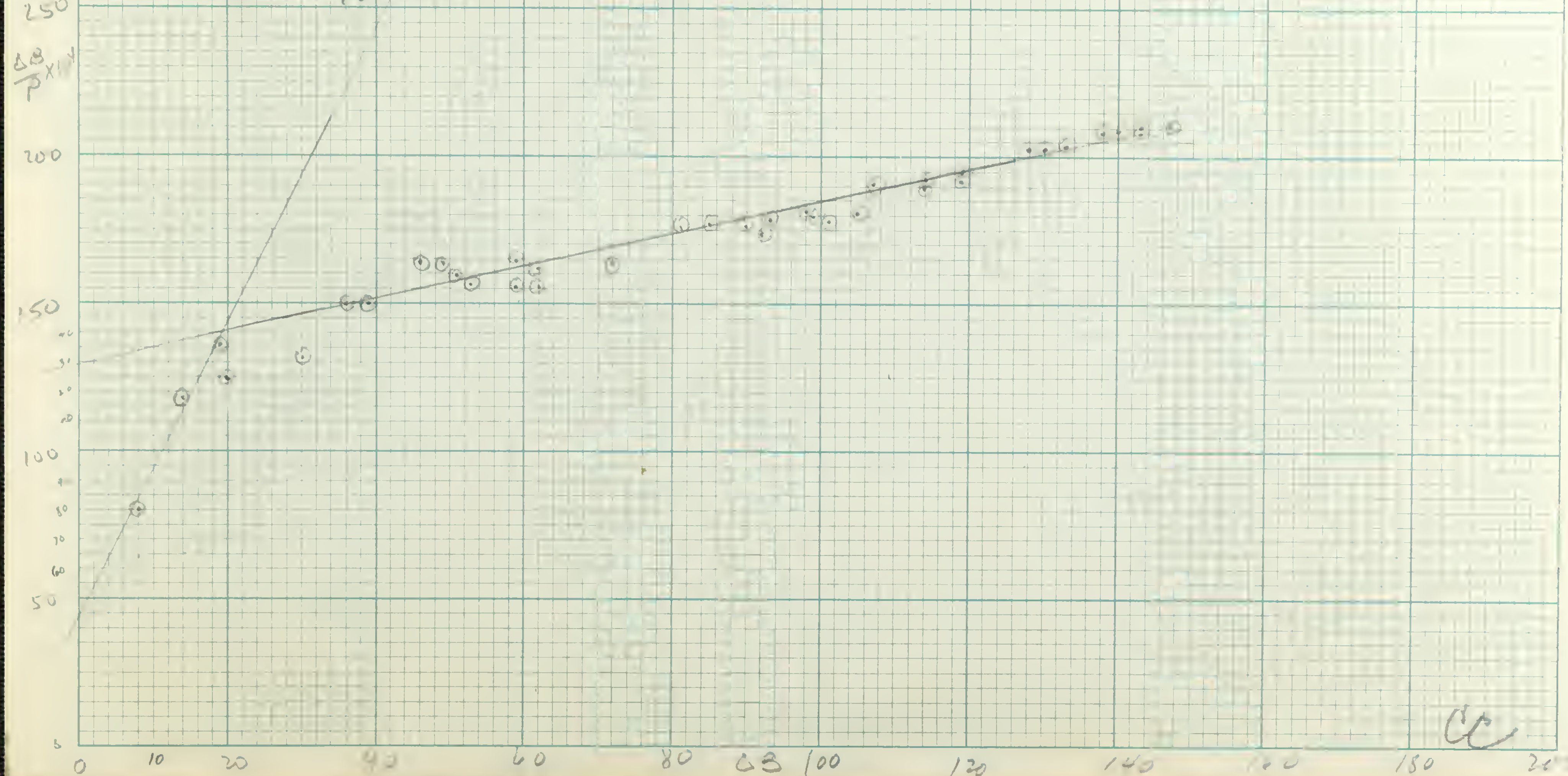
SHEET 10 RUN 3

$\frac{\Delta B}{P}$ VS ΔB

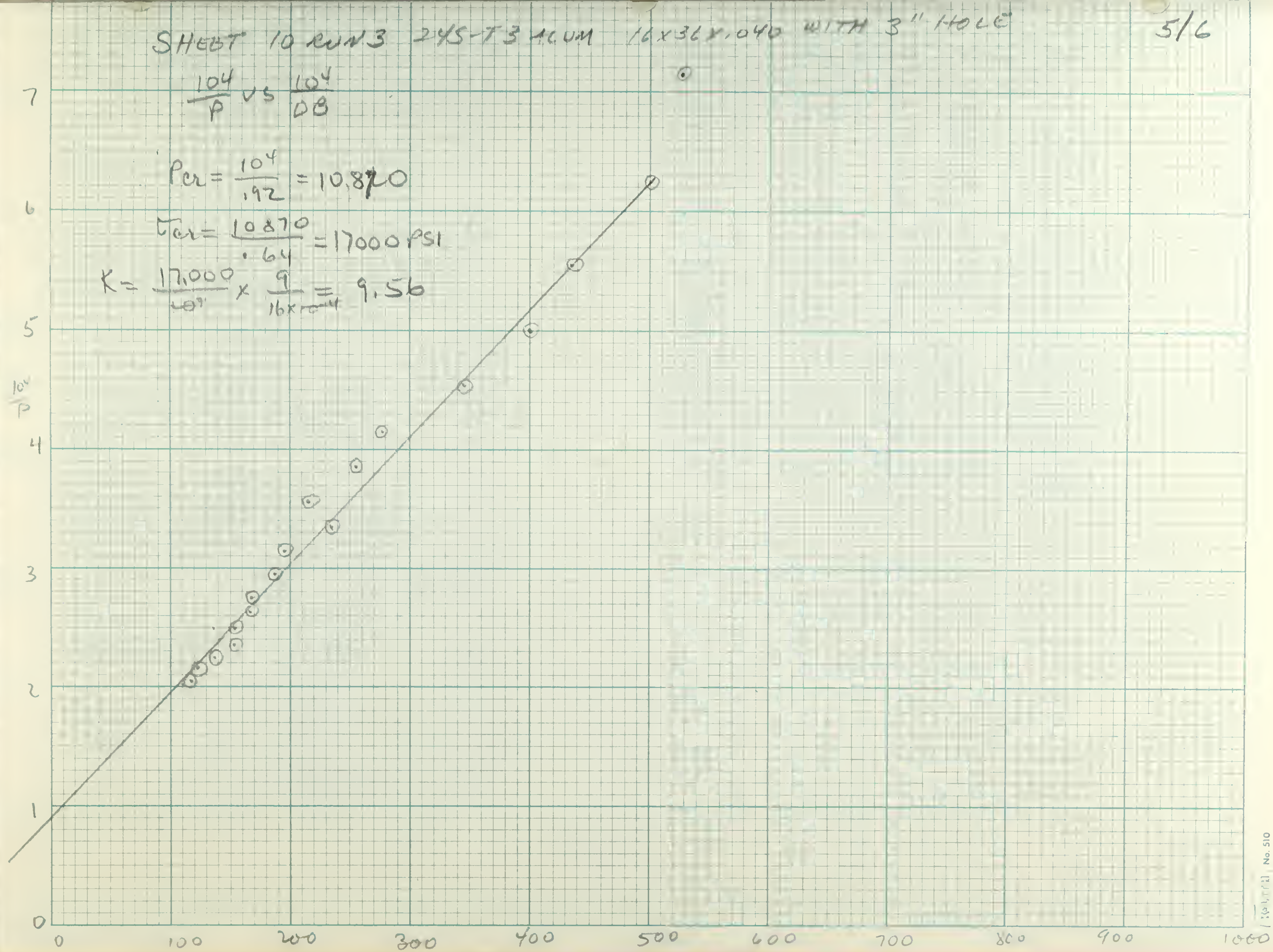
$P_a = \frac{100}{206-152} = \frac{100}{54} = 18{,}500$ LBS.

$\sigma_a = \frac{18500}{164} = 28{,}900$ PSI

$K = 28{,}900 \times \frac{9}{16} = \underline{16{,}25}$



No. 510


SHEET 10 RUN 3 24S-T3 ALUM 16x36x.040 WITH 3" HOLE
5/6
$\frac{10^4}{P}$ vs $\frac{10^4}{\delta B}$
$P_{cr} = \frac{10^4}{.92} = 10,870$
$\tau_{cr} = \frac{10870}{.64} = 17000$ PSI
$K = \frac{17,000}{10^7} \times \frac{9}{16 \times 10^{-4}} = 9.56$
$\frac{10^4}{P}$
0
1
2
3
4
5
6
7
0
100
200
300
400
500
600
700
800
900
1000
No. 510

P	$\frac{10^4}{P}$	B	ΔB	$\frac{\Delta B}{P} \times 10^4$	$\frac{10^4}{\Delta B}$	T	ΔT	STRESS
0	↓	1518			↓	340		
100	100	1499	19	1900	526	398		
200	50	1499	19	950	526	459		
300	33.3	1494	24	800	417	521		
400	25	1482	36	900	278	572		
500	20	1464	54	508	185	632		
600	16.7	1432	86	1433	116	690		
700	14.3	1400	118	1685	84.7	750		
800	12.5	1342	176	2200	56.8	818		
900	11.1	1275	243	2700	41.2	879		
1000	10.0	1189	329	3290	30.4	945		
1100	9.09	1093	425	3860	23.5	1008		
1200	8.33	986	532	4430	18.8	1172		
1300	7.69	876	642	4940	15.6	1139		
1400	7.14	772	746	5330	13.4	1200		
1500	6.67	658	860	5730	11.6	1267		
1600	6.24	546	972	6080	10.3	1332		
1700	5.88	442	1076	6330	9.30	1395		
1800	5.56	327	1191	6620	8.39	1463		
1900	5.76	231	1287	6770	7.79	1528		
2000	5.00	128	1390	6950	7.19	1595		
2100	4.76	18	1500	7142	6.67	1666		
2200	4.54	1925	1593	7240	6.27	1725		
2300	4.35	1819	1699	7390	5.88	1799		
2400	4.16	1722	1796	7480	5.56	1864		
2500	4.00	1620	1898	7590	5.27	1937		

P	$\frac{10^4}{P}$	B	ΔB	$\frac{\Delta B}{P} \times 10^4$	$\frac{10^4}{\Delta B}$	T	ΔT	STRESS
2600	3.84	1524	1994	7670	5.01	2002		
2700	3.70	1435	2083	7710	4.79	2073		
2800	3.57	1347	2171	7750	4.60	2142		
2900	3.44	1260	2258	7790	4.42	2208		
3000	3.33	1168	2350	7830	4.26	2280		
3100	3.23	1082	2436	7860	4.10	2349		
3200	3.13	1000	2518	7870	3.96	2416		
3300	3.03	905	2613	7920	3.83	2488		
3400	2.94	825	2693	7920	3.70	2558		
3500	2.86	735	2783	7951	3.59	2632		
3600	2.78	652	2866	7961	3.49	2700		
3700	2.70	567	2951	7980	3.38	2772		
3800	2.63	482	3036	7990	3.29	2849		
3900	2.56	400	3118	7990	3.20	2918		
4000	2.50	310	3208	8020	3.12	3000		

FF

$50000\,PSI \times .020 \times 16 = .32 \times 5 \times 10^4 = 1.6 \times 10^4$

$\frac{16{,}000 \text{ LBS LOAD}}{3} = 5333$ LBS LOAD TO CAUSE YIELD AT MAX STRESS POINT ON HOLE

SHEET 11 RUN 1 24 S-T3 ALUMINUM 16 x 36 x .020" WITH 3" HOLE

5/13/57

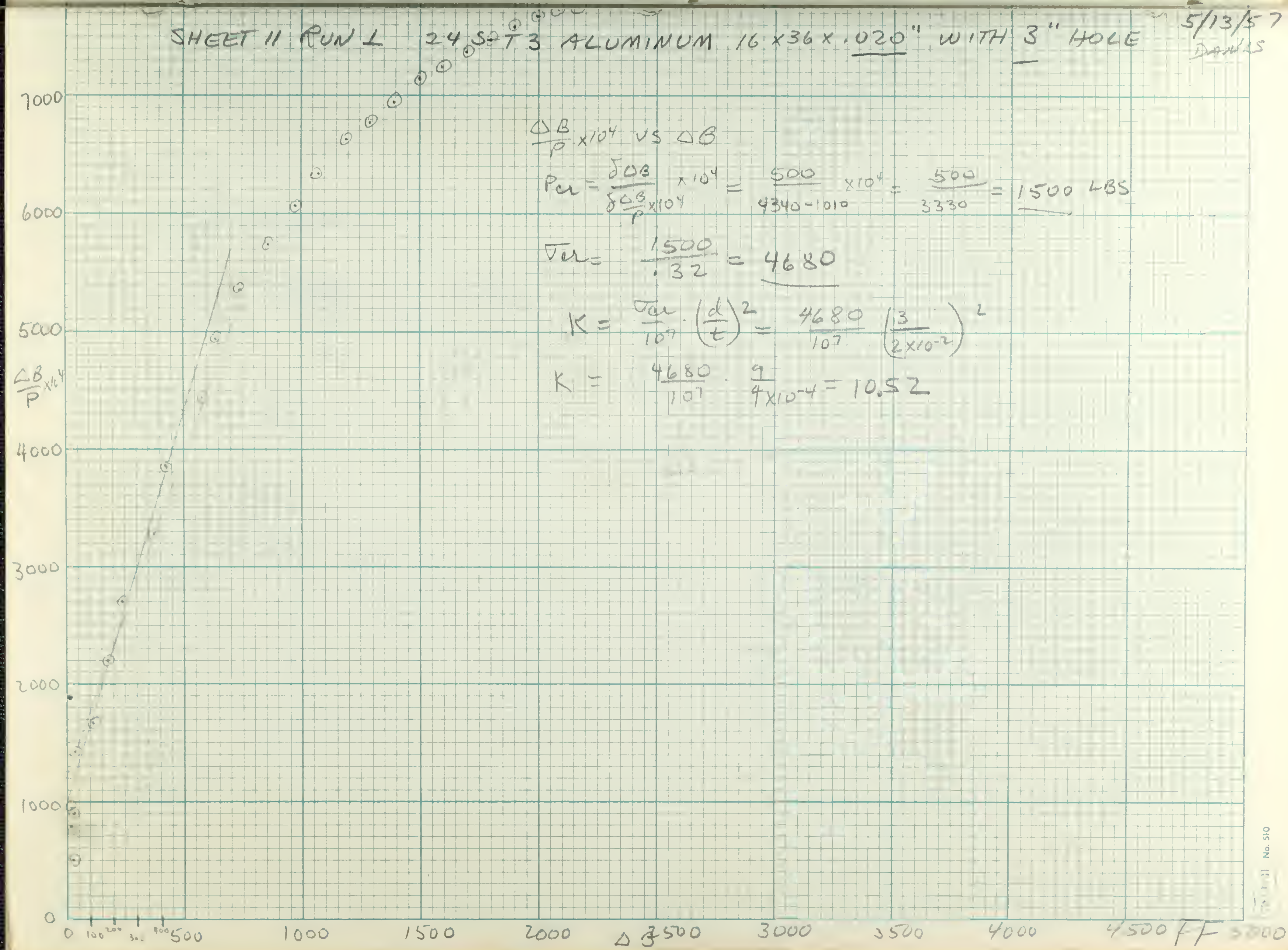
$\frac{\Delta B}{P} \times 10^4$ VS ΔB

$$P_{cr} = \frac{\delta \Delta B}{\delta \frac{\Delta B}{P} \times 10^4} \times 10^4 = \frac{500}{4340-1010} \times 10^4 = \frac{500}{3330} = \underline{1500 \text{ LBS}}$$

$$\sigma_{cr} = \frac{1500}{.32} = \underline{4680}$$

$$K = \frac{\sigma_{cr}}{10^7} \cdot \left(\frac{d}{t}\right)^2 = \frac{4680}{10^7} \left(\frac{3}{2 \times 10^{-2}}\right)^2$$

$$K = \frac{4680}{10^7} \cdot \frac{9}{4 \times 10^{-4}} = 10.52$$



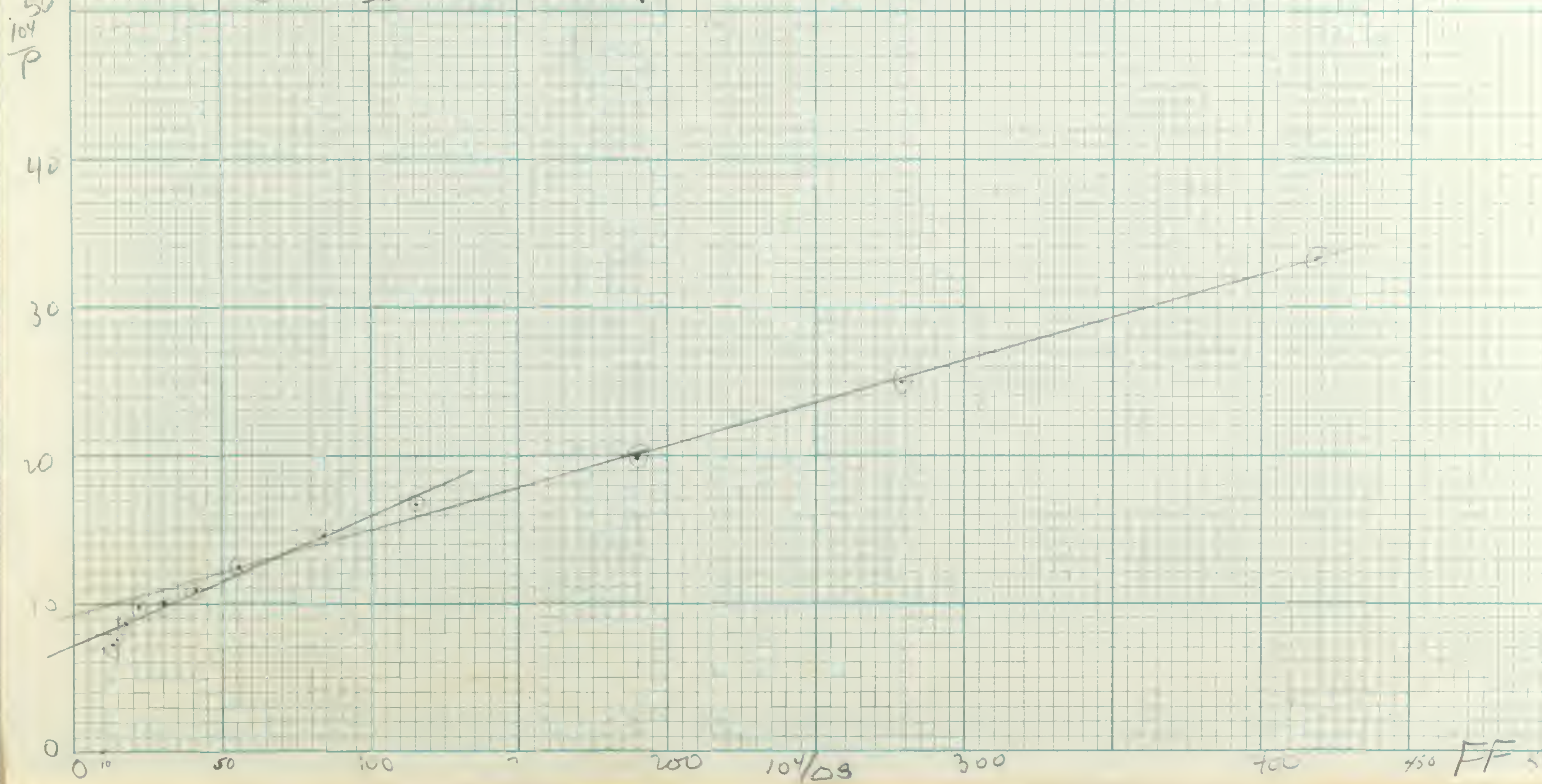
SHEET 11 RUN 1

$\frac{10^4}{P}$ VS $\frac{10^4}{\Delta B}$

P_{cr} $\frac{10^4}{7.2} = 1388$ LBS

$\sigma_{cr} = \frac{1388}{.32} = 4330$ PSI

$K = \frac{\sigma_{cr}}{E} \times \left(\frac{d}{t}\right)^2 = \frac{4.330}{\cancel{10^7}} \times \frac{9}{4 \times \cancel{10^{-4}}} = 9.74$



P	$\frac{1}{P}$	B	ΔB	$\frac{\Delta B}{P} \times 10^4$	$\frac{1}{\Delta B}$	T	ΔT	STRESS
0		2530				300		
100	100	2490	40	4000	250	370		
200	50	2488	42	2100	238	430		
300	33	2480	50	1670	200	490		
400	25	2472	58	1450	172	558		
500	20	2452	78	1560	128	618		
600	16.7	2422	108	1800	92.6	685		
700	14.3	2380	150	2140	66.7	752		
750		2362	168	2240	59.5	762		
800	12.5	2325	[illegible]	2560	49.0	812		
850		2300	230	2710	43.5	840		
900	11.1	2264	266	2960	37.6	~~964~~		
950		2219	311	3270	32.2	908		
1000	10.0	2175	355	3550	28.2	941		
1050		2139	391	3720	25.6	965		
1100	9.09	2081	449	4080	22.3	1005		
1150		1982	548	4770	21.0	1038		
1200	8.33	1931	[illegible]	14990	16.7	1069		
1250		1872	658	5260	15.2	1102		
1300	7.69	1791	739	5680	13.5	1138		
1400	7.14	1666	864	6170	11.6	1201		
1500	6.67	1558	972	6480	10.3	1268		
1600	6.24	1452	1078	6740	9.26	1335		
1700	5.88	1330	1200	7060	8.33	1405		
1800	5.56	1222	1308	7270	7.63	1472		
1900	5.76	1096	1434	7550	6.99	1534		

P	$\frac{1}{P}$	B	ΔB	$\frac{\Delta B}{P} \times 10^4$	$\frac{1}{\Delta B}$	T	ΔT	STRESS
2000	5.00	1028	1502	7510	6.67	1600		
2100	4.76	912	1618	7700		1675		
2200	4.54	818	1712	7780		1741		
2300	4.35	720	1810	7870		1810		
2400	4.16	622	1908	7950		1880		
2500	4.00	515	2015	8060		1952		
2600	3.84	435	2095	8060		2020		
2700	3.70	318	2212	8190		2089		
2800	3.57	218	2312	8260		2160		
2900	3.44	142	2388	8230		2228		
3000	3.33	045	2485	8280		2315		

GG

SHEET #RCW2 16 x 36 x .020" WITH 3" HOLE 24S-T3 ALUM 5/14

$\frac{10^4}{P}$ vs $\frac{10^4}{\Delta B}$

$P_{cr} = \frac{10^4}{8.2} = 1220$ LBS

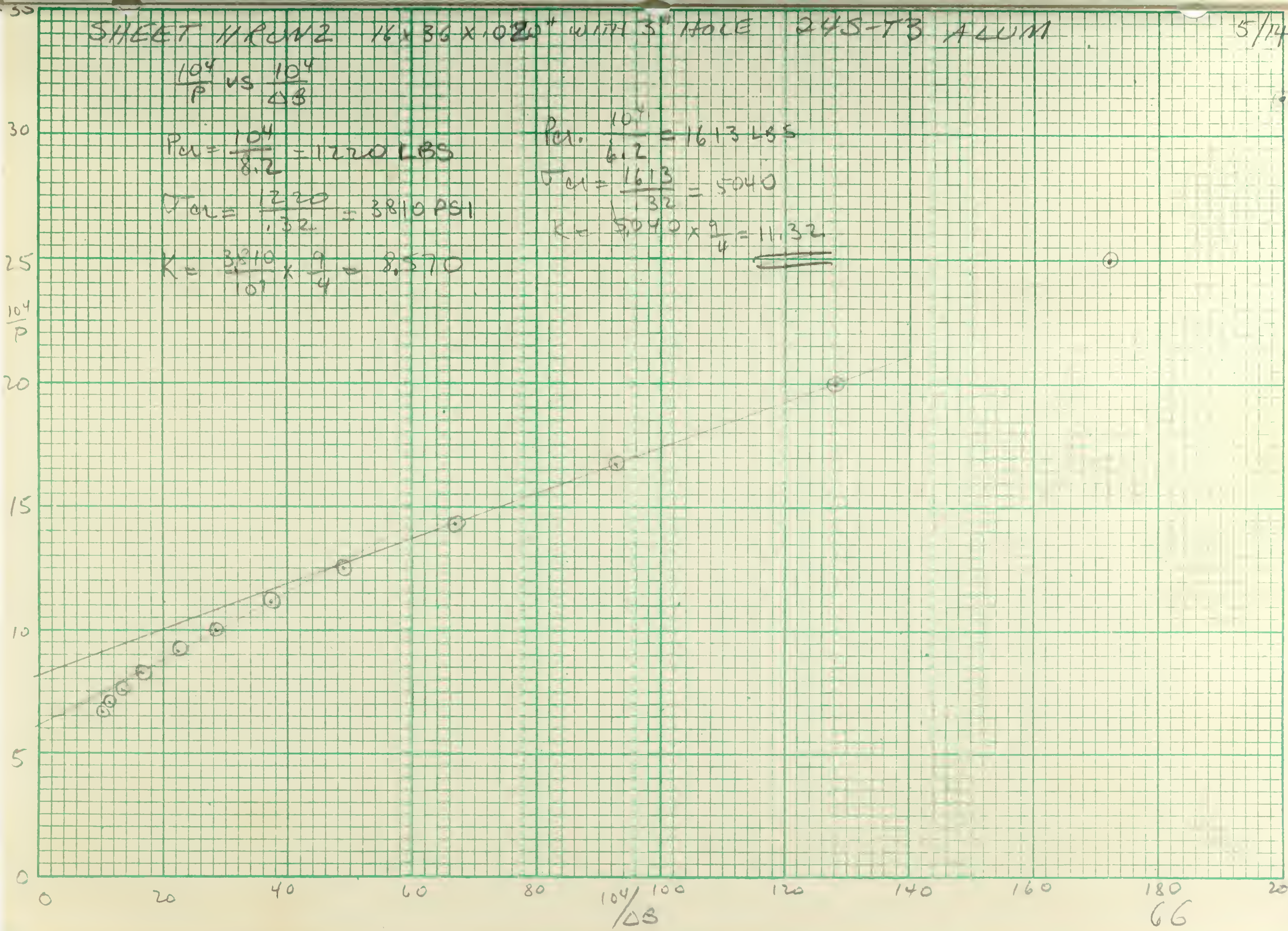
$\sigma_{cr} = \frac{1220}{.32} = 3810$ PSI

$K = \frac{3810}{10^7} \times \frac{9}{4} = 8.570$

$P_{cr.} \frac{10^4}{6.2} = 1613$ LBS

$\sigma_{cr} = \frac{1613}{.32} = 5040$

$K = \frac{5040}{} \times \frac{9}{4} = \underline{\underline{11.32}}$



66

SHEET 11 RUN 2 16 x 36 x .020" WITH 3" HOLE 24S-T3 ALUM

DAVIS 5/14

$\frac{\Delta B}{P}$ vs ΔB

$P_{cr} = \frac{\delta \Delta B}{\delta \frac{\Delta B}{P}} \times 10^4$

$= \frac{600}{5190-1180} \times 10^4$

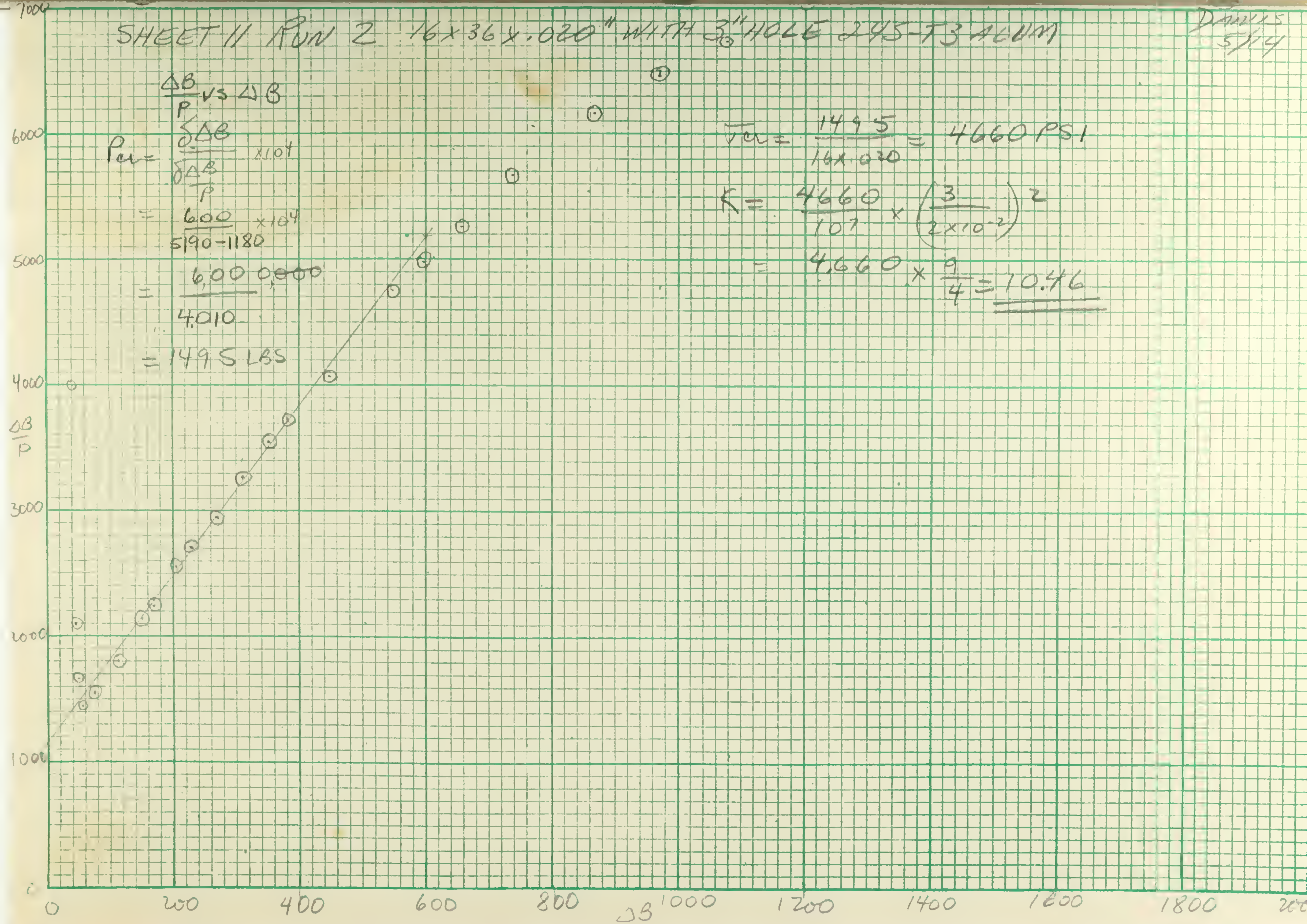
$= \frac{6{,}000{,}000}{4{,}010}$

$= 1495$ LBS

$\sigma_{cr} = \frac{1495}{16 \times .020} = 4660$ PSI

$K = \frac{4660}{10^7} \times \left(\frac{3}{2 \times 10^{-2}}\right)^2$

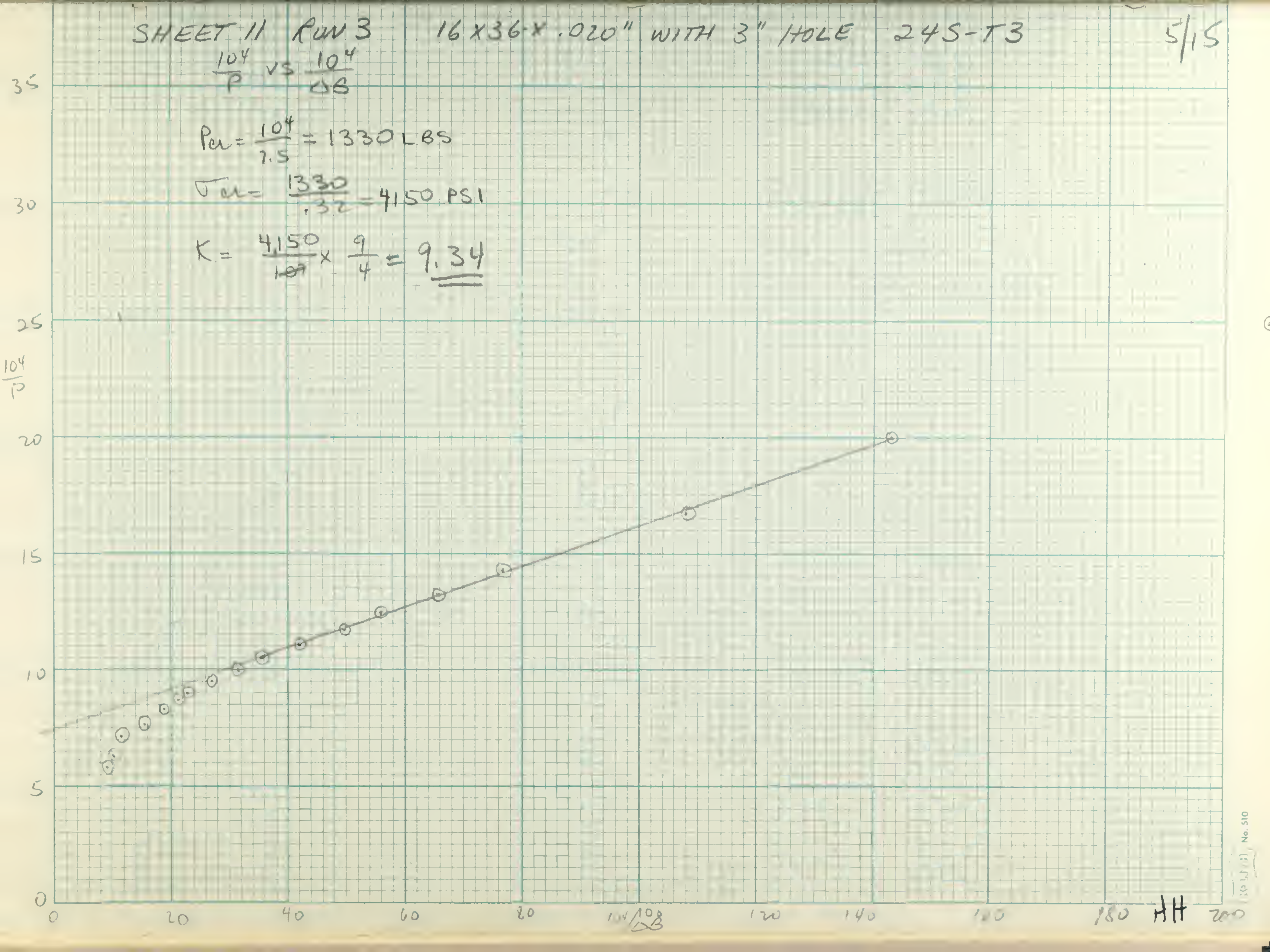
$= 4{,}660 \times \frac{9}{4} = \underline{\underline{10.46}}$



P	1/P	D	ΔD	[illegible]	ΔB
0		2430	—		
100	100	2396	34	3400	294
200	50	2395	35	1750	286
300	33.3	2395	35	1170	286
400	25	2382	48	1200	208
500	20	2360	70	1400	143
600	16.7	2338	92	1530	108
700	14.3	2300	130	1860	[illegible]
750	13.3	2278	152	2026	[illegible]
800	12.5	2251	179	2240	55.9
850	11.7	2228	[illegible]	2380	[illegible]
900	11.1	2192	[illegible]	2640	[illegible]
950	10.5	2151	[illegible]	2940	[illegible]
1000	10.0	2114	316	3160	[illegible]
1050	9.52	2062	368	3500	[illegible]
1100	9.09	2003	437	3970	22.9
1150	8.69	1968	462	4010	21.6
1200	8.33	1902	528	4400	18.9
1300	7.69	1794	636	4890	15.7
1400	7.14	1685	745	5320	13.4
1500	6.67	1570	860	5730	11.6
1600	6.25	1458	972	6060	10.3
1700	5.88	1350	1080	6350	9.26
1800	5.56	1237	1197	6650	8.55
1900	5.26	1132	1298	6830	7.70
2000	5.00	1028	1402	7001	7.13

[illegible]	[illegible]	D	ΔD	[illegible]	ΔB
2100	4.76	924	1506	7180	6.64
2200	4.54	826	1604	7290	6.23
2300	4.35	732	1698	7380	5.89
2400	4.16	636	1794	7480	5.57
2500	4.00	538	1892	7580	5.29
2600	3.84	441	1989	7650	5.03
2700	3.70	349	2081	7720	4.81
2800	3.57	251	2179	7820	4.51
2900	3.44	168	2262	7820	4.42
3000	3.33	62	2368	7900	4.22

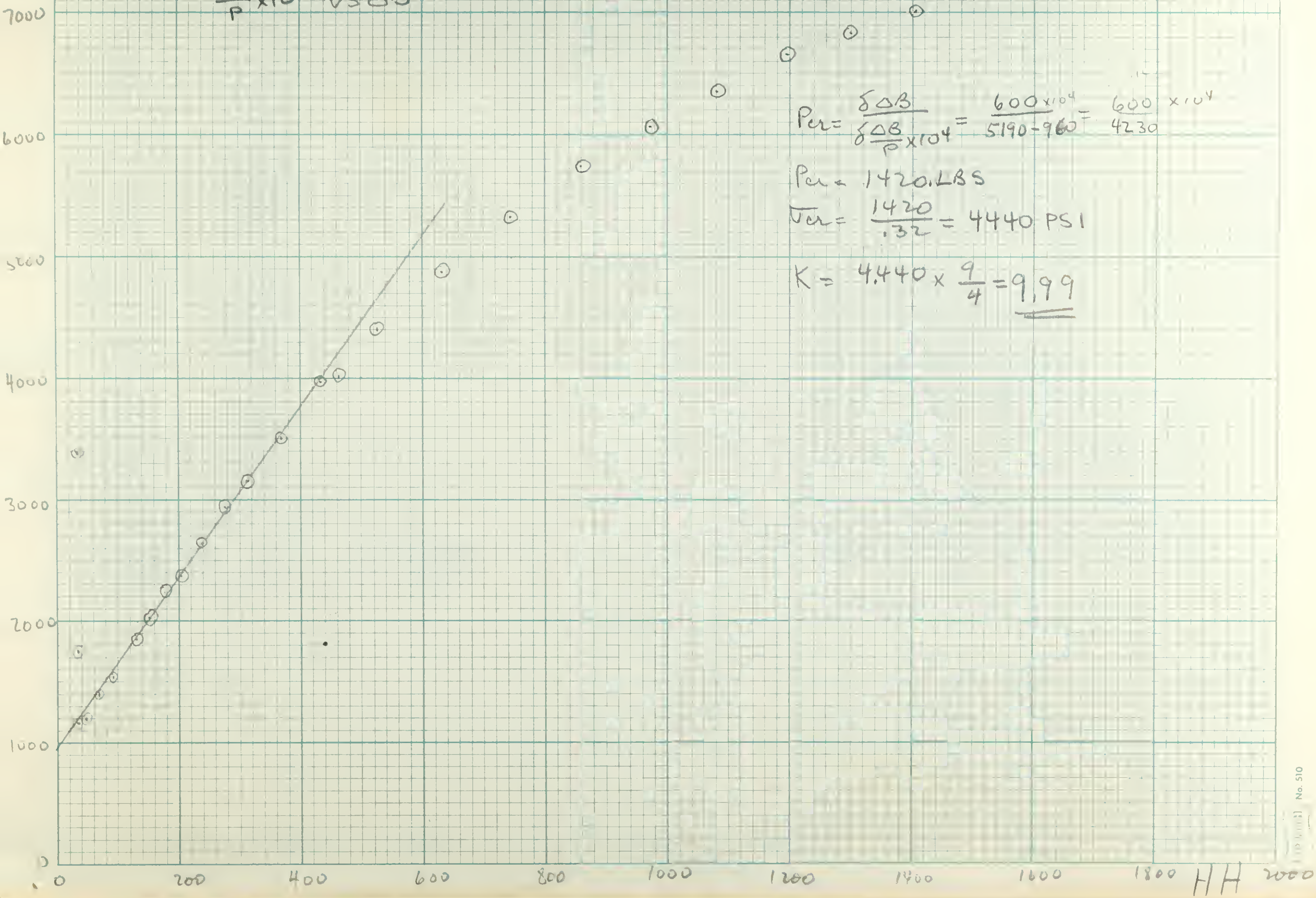
HH


SHEET 11 RUN 3 16 x 36 x .020" WITH 3" HOLE 24S-T3
5/15
$\frac{10^4}{P}$ VS $\frac{10^4}{\Delta B}$
$P_{cr} = \frac{10^4}{7.5} = 1330$ LBS
$\sigma_{cr} = \frac{1330}{.32} = 4150$ PSI
$K = \frac{4150}{10^7} \times \frac{9}{4} = 9.34$
$\frac{10^4}{P}$
$10^4/\Delta B$
0
5
10
15
20
25
30
35
0
20
40
60
80
120
140
180
200
HH
No. 510

SHEET 11 RUN 3 24S-T3 ALUM 16 X 36 X .020" WITH 3" HOLE

5/15

$\frac{\Delta B}{P} \times 10^4$ VS ΔB



$P_{cr} = \frac{\delta \Delta B}{\delta \frac{\Delta B}{P} \times 10^4} = \frac{600 \times 10^4}{5190 - 960} = \frac{600}{4230} \times 10^4$

$P_{cr} = 1420$ LBS

$\sigma_{cr} = \frac{1420}{.32} = 4440$ PSI

$K = 4.440 \times \frac{9}{4} = \underline{\underline{9.99}}$

P	ρ	B	ΔB	P	ΔB
0		1182			
100		1150			
200		1141			
300		1152			
400		1168			
500		1225			
600		1282			
700		1360			
800		1442			
900		1511			
1000		1588			
1100		1662			
1200		1715			
1300		1768			
1400		1801			
1500		1830			
1600		1856			
1700		1856			
1800	5.56	1855	0	–	
1900	5.76	1850	5	263	2000
2000	5.90	1828	27	135.	370

P	ρ	B	ΔB	P	ΔB	ΔP	$\frac{ΔP}{P} \times 10$
2100	4.76	1810	45	214	222		
2200	4.54	1773	82	373	122		
2300	4.35	1732	123	534	81.3		
2400	4.16	1685	170	708	58.8		
2500	4.00	1624	231	924	43.3		
2600	3.84	1572	283	1088	35.3		
2700	3.70	1499	356	1320	28.1		
2800	3.57	1422	433	1550	23.1		
2900	3.44	1368	487	1680	20.5		
3000	3.33	1315	540	1800	18.5		
3100	3.23	1270	585	1887	17.1		
3200	3.13	1238	617	1928	16.2		
3300	3.03	1209	646	1957	15.5		
3400	2.94	1196	659	1938	15.2		
3500	2.86	1174	681	1945	14.7	8	22.5
3600	2.78	1156	699	1941	14.3	26	72.2
3700	2.70	1145	710	1918	14.1	37	100
3800	2.63	1132	723	1902	13.8	50	132
3900	2.56	1112	743	1905	13.4	60	154
4000	2.50	1100	755	1887	13.2	82	205

II

$$P = \tau A$$

$$P = \frac{50000}{3} \times .020 \times 16$$

$$P = \frac{5000\cancel{0}}{\cancel{3}} \times .\overset{10}{\cancel{32}} \text{ lbs } \underline{\underline{max}}$$

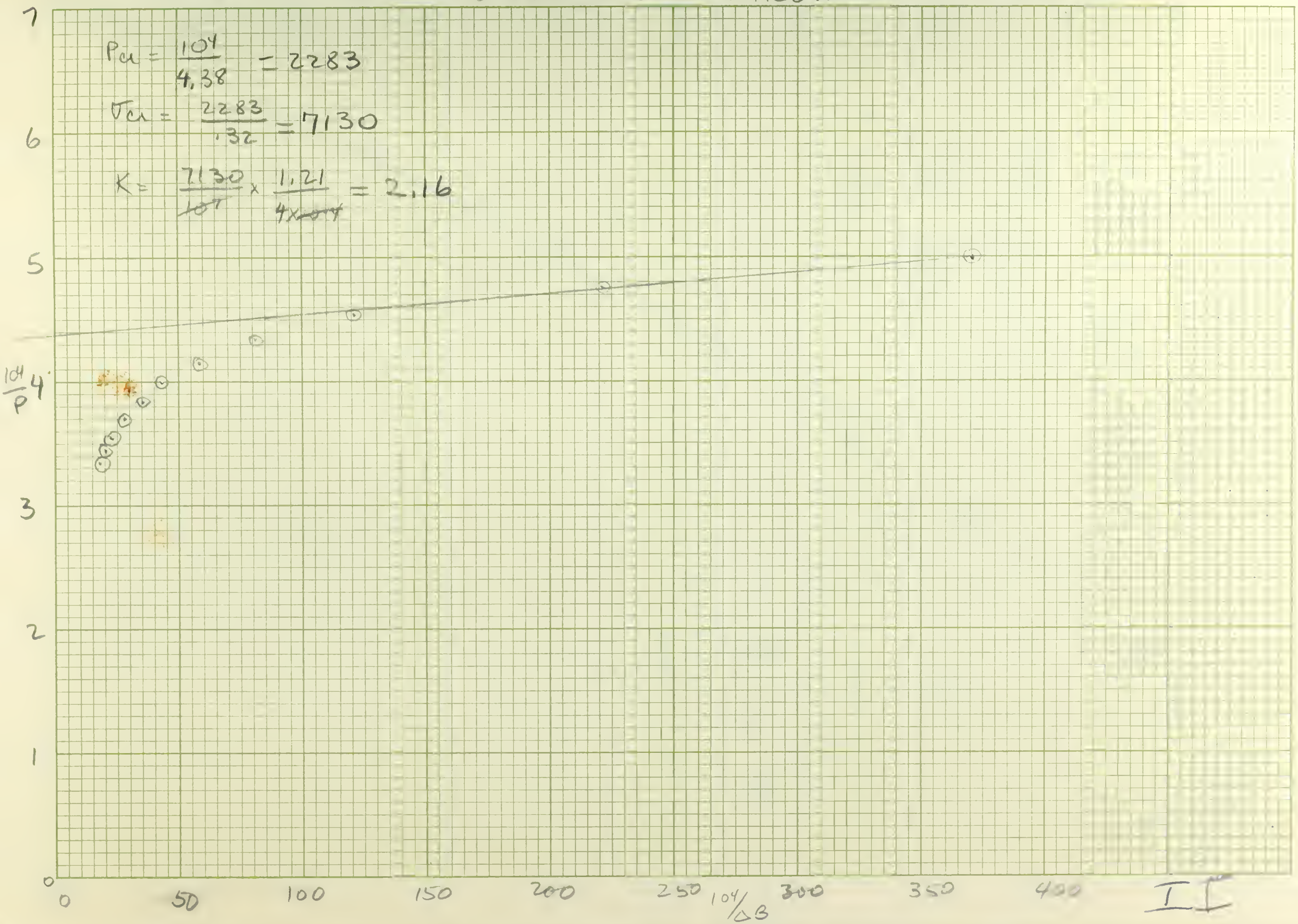
USE 4,000

SHEET 12 RUN ⊥ 16X36X.020' 24 S-T3 ALUM WITH 1.1" HOLE 5/17

$$P_{cr} = \frac{10^4}{4.38} = 2283$$

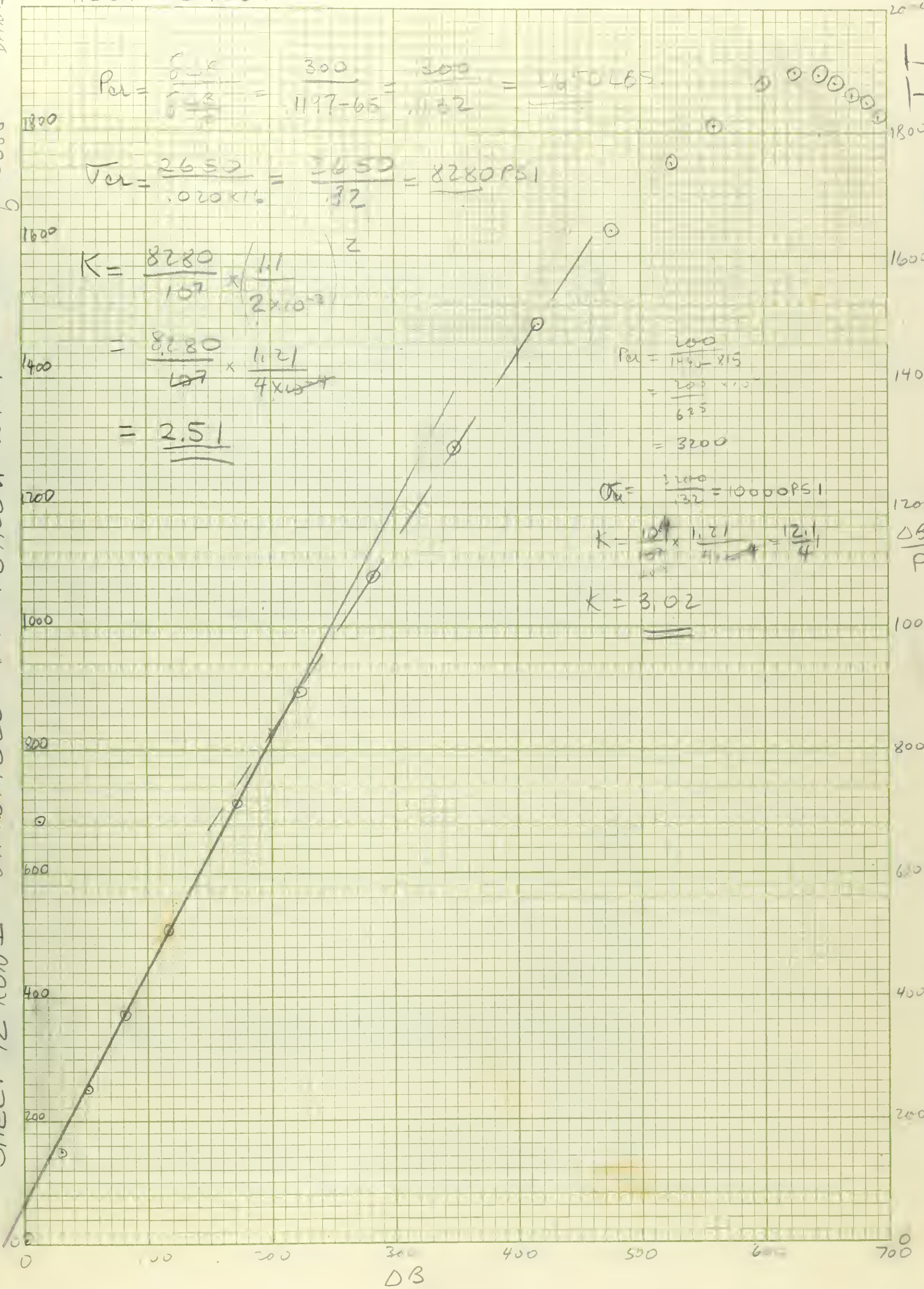
$$\sigma_{cr} = \frac{2283}{.32} = 7130$$

$$K = \frac{7130}{\cancel{10^7}} \times \frac{1.21}{4 \times \cancel{.04}} = 2.16$$



SHEET 12 RUN 1   1.1" HOLE   .020" THICK -   5/17

SHEET 12 RUN 1   16 x 30 x .020"   24S-T3 ALUM WITH 1.1" HOLE $\frac{1}{b}$ .0688   5/11 DAVIS



$P_{cr} = \frac{300}{1197-65} = \frac{300}{.132} = 2270 \text{ LBS}$

$\sigma_{cr} = \frac{2650}{.020 \times 16} = \frac{2650}{.32} = \underline{8280 \text{ PSI}}$

$K = \frac{8280}{10^7} \times \left(\frac{1.1}{2 \times 10^{-2}}\right)^2$

$= \frac{8280}{\cancel{10^7}} \times \frac{1.21}{4 \times \cancel{10^{-4}}}$

$= \underline{\underline{2.51}}$

$P_{cr} = \frac{200}{1440-815} = \frac{200}{625} \times 10 = 3200$

$\sigma_{cr} = \frac{3200}{.32} = 10000 \text{ PSI}$

$K = \frac{10^4}{10^7} \times \frac{1.21}{4 \times 10^{-4}} = \frac{12.1}{4}$

$\underline{\underline{K = 3.02}}$

$\frac{\Delta B}{P} \times 10$

ΔB

P	1/P	B	ΔB	$\overline{P}$	$\overline{\Delta B}$
0		1202			
100		1180			
200		1172			
300		1176			
400		1212			
500		1262			
600		1312			
700		1390			
800		1472			
900		1542			
1000		1618			
1100		1688			
1200		1753			
1300		1802			
1400		1842			
1500		1875			
1600		1892			
1700		1905	0	-	
1800	5.56	1904	[illegible]	6	
1900	5.76	1892	13	684	769
2000	5.00	1875	30	150	333

P	1/P	B	ΔB	$\overline{P}$	$\overline{\Delta B}$
2100	4.76	1862	53	252	189
2200	4.54	1823	82	373	122
2300	4.35	1788	117	508	85.5
2400	4.16	1733	172	716	58.1
2500	4.00	1682	223	892	44.9
2600	3.84	1623	282	1080	35.5
2700	3.70	1556	349	1290	28.6
2800	3.57	1489	416	1490	24.0
2900	3.44	1424	476	1640	21.0
3000	3.33	1380	525	1750	19.0
3100	3.23	1345	560	1810	17.8
3200	3.13	1305	600	1880	[illegible]
3300	3.03	1279	626	1896	16.0
3400	2.94	1262	643	1890	15.5
3500	2.86	1246	659	1880	15.2
3600	2.78	1234	671	1860	14.9
3700	2.70	1220	685	1850	14.6
3800	2.63	1211	694	1826	14.4
3900	2.56	1201	704	1805	14.2
4000	2.50	1189	716	1790	14.0

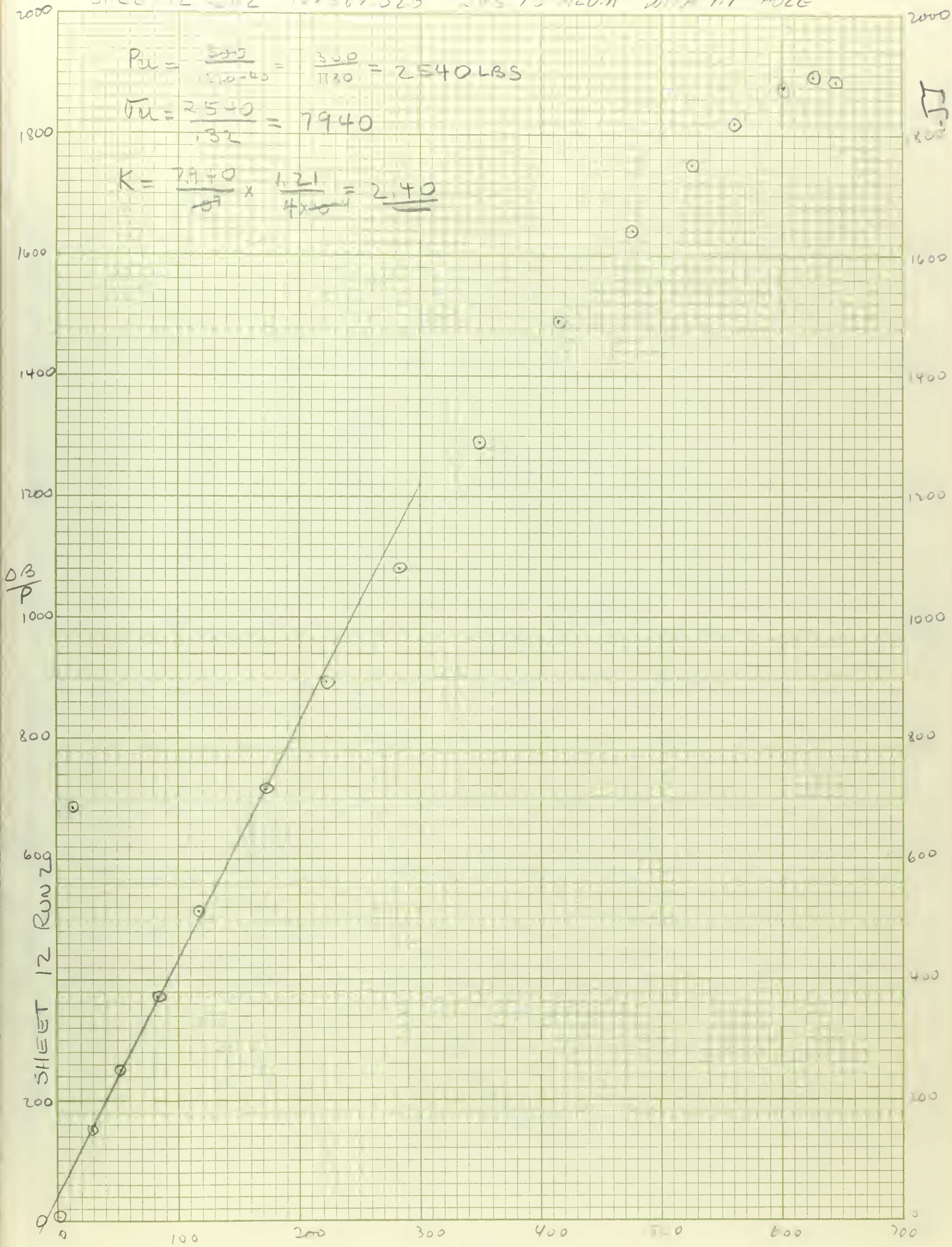
JJ

SHEET 12 RUN 2   12×36×.020" 24S T3 ALUM WITH 1.1" HOLE   5/17

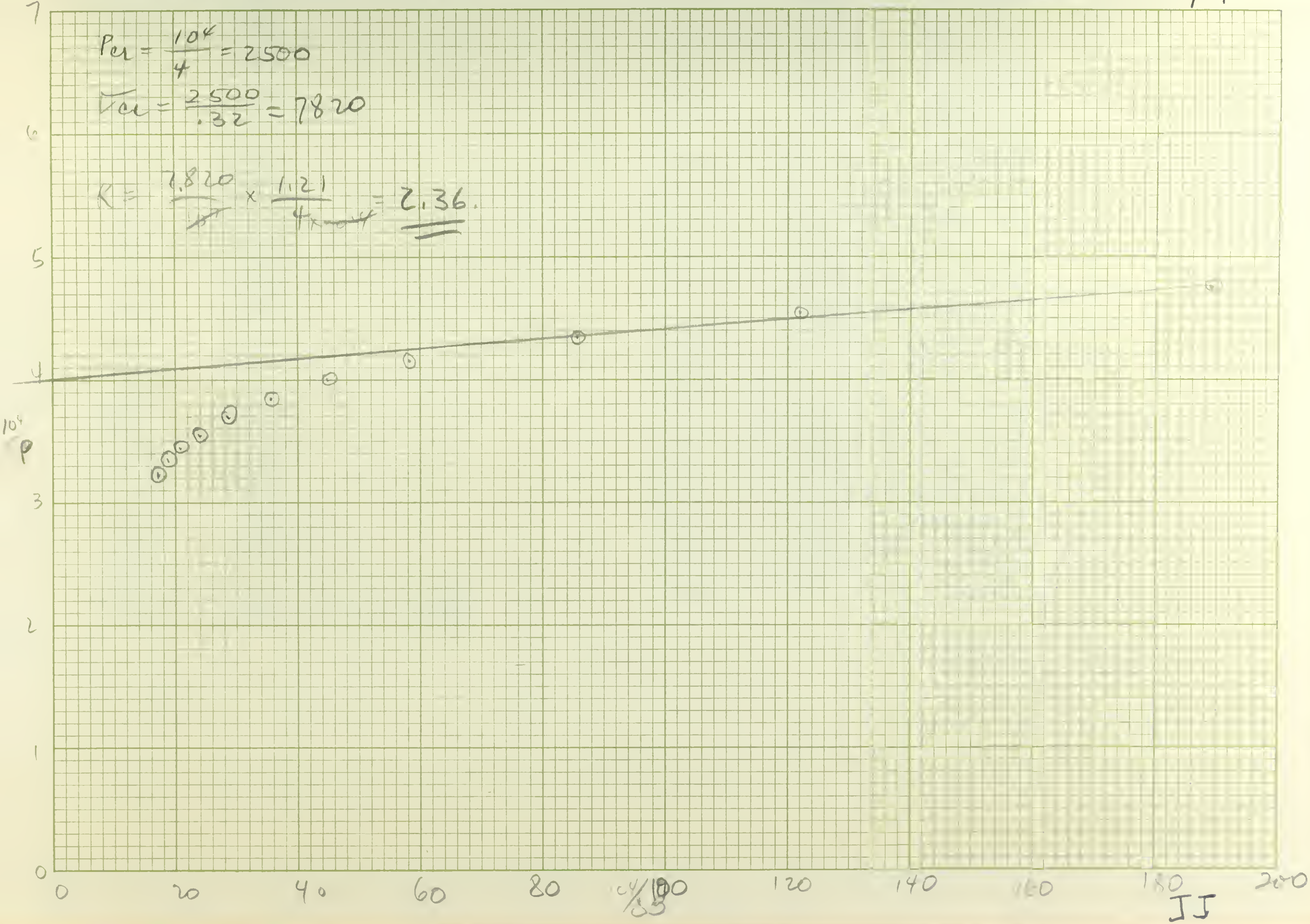
$P_u = \frac{300}{[illegible]} = \frac{300}{.1180} = 2540 \text{ LBS}$

$\sigma_u = \frac{2540}{.32} = 7940$

$K = \frac{7940}{[illegible]} \times \frac{1.21}{4 \times [illegible]} = \underline{\underline{2.40}}$



SHEET 12 RUN 2 16 x 36 x .020" WITH 1.1" HOLE 24S-T3 ALUM 5/17



P	$10^4/P$	B	ΔB	$\frac{\Delta B}{P}\times 10^4$	$\frac{10^4}{\Delta B}$
0		1228			
100		1292			
200		1195			
300		1202			
400		1225			
500		1273			
600		1348			
700		1412			
800		1482			
900		1562			
1000		1637			
1100		1710			
1200		1772			
1300		1826			
1400		1874			
1500		1901			
1600		1918			
1700		1932	0		
1800		1932	0		
1900	5.76	1918	14	73.0	714
2000	5.00	1900	32	160	313

P	$10^4/P$	B	ΔB	$\frac{\Delta B}{P}\times 10^4$	$\frac{10^4}{\Delta B}$
2100	4.76	1882	50	238	200
2200	4.54	1843	89	404	112
2300	4.35	1809	123	535	81.3
2400	4.16	1758	174	725	57.5
2500	4.00	1708	224	895	44.6
2600	3.84	1642	290	1115	34.5
2700	3.70	1587	345	1276	29.0
2800	3.57	1510	422	1505	27.6
2900	3.44	1458	474	1634	21.1
3000	3.33	1400	532	1772	18.8
3100	3.23	1362	570	1838	17.5
3200	3.13	1331	601	1880	16.6
3300	3.03	1311	621	1885	16.1
3400	2.94	1293	639	1880	15.6
3500	2.86	1277	655	1872	15.3
3600	2.78	1258	674	1870	14.8
3700	2.70	1248	684	1848	14.6
3800	2.63	1232	700	1840	14.3
3900	2.56	1228	704		14.2
4000	2.50	1215	717		13.9

KK

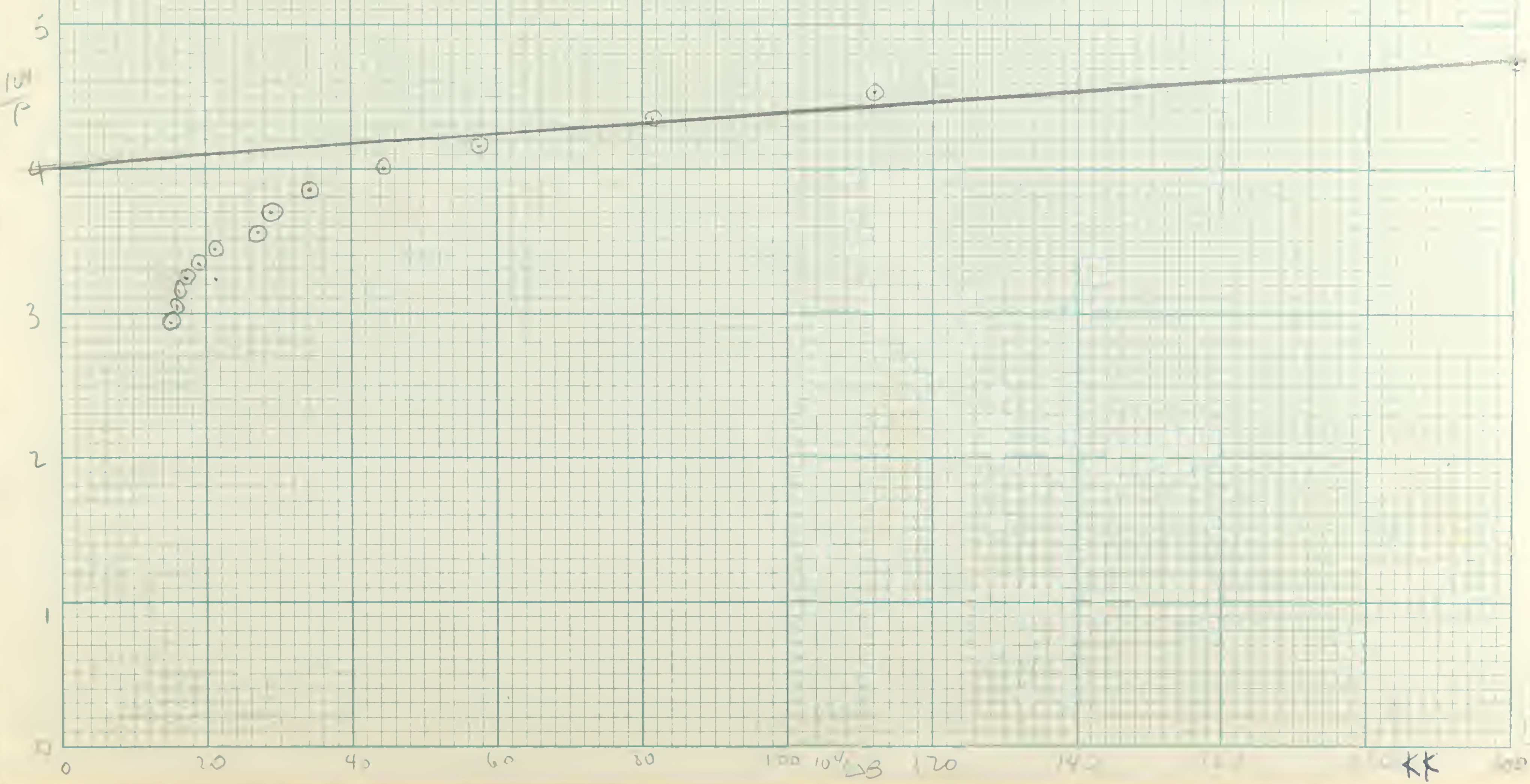
5/17

SHEET 12 RUN 3 16 X 36 X .020" 24S-T3 ALUM WITH 1.1" HOLE.

$P_{cr} = \frac{10^4}{4.04} = 2475$ LBS

$\sigma_{cr} = \frac{2475}{.32} = 7740$ PSI

$K = \frac{7740}{10^7} \times \frac{1.21}{4 \times 10^{-4}} = \underline{\underline{2.34}}$



SHEET 12 RUN 3 16×36×.020" 24S-T3 ALUM 5/17
WITH 1.1" HOLE

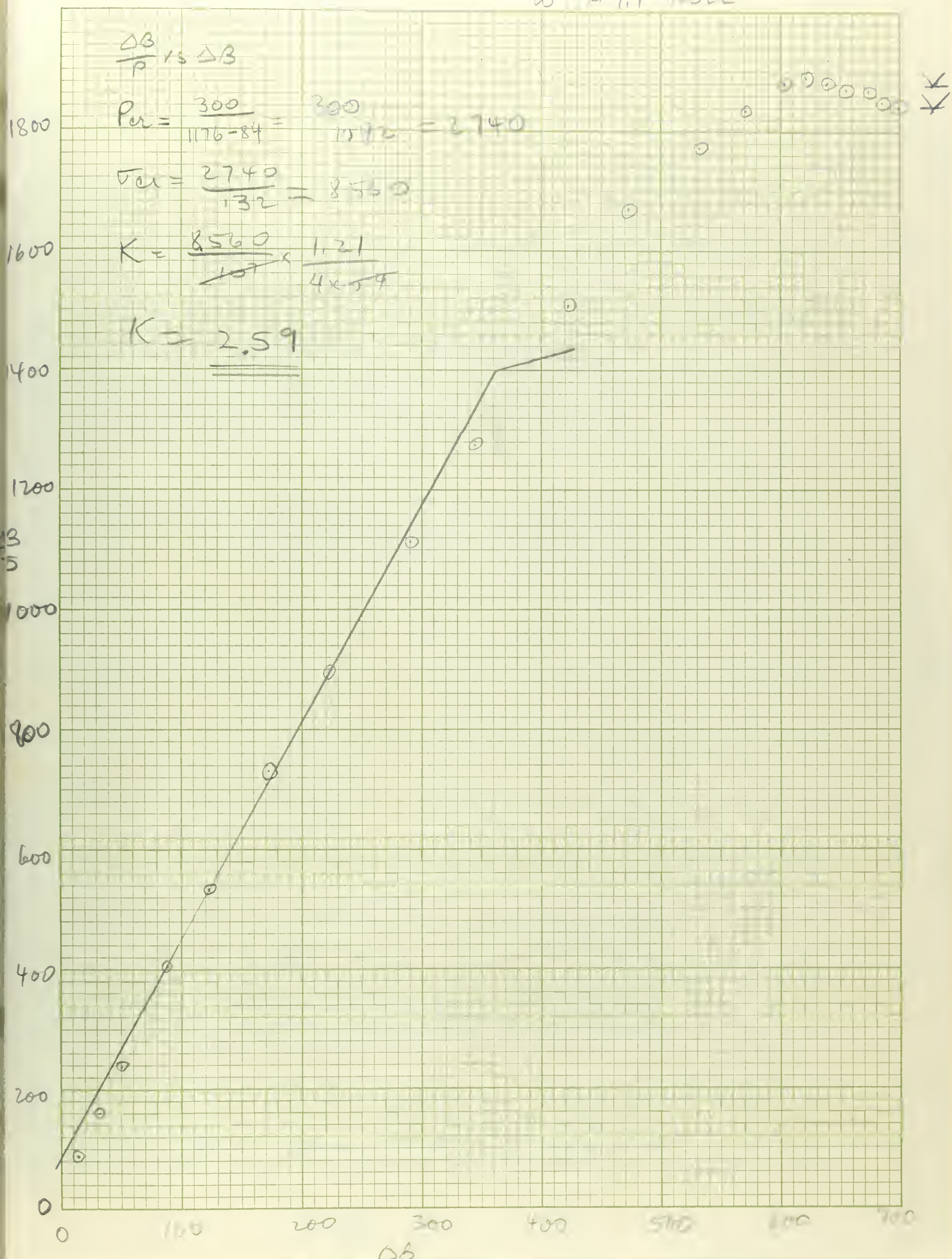
$\frac{\Delta B}{P}$ vs ΔB

$P_{cr} = \frac{300}{1176-84} = \frac{300}{1092} = 2740$

$\sigma_{cr} = \frac{2740}{.132} = 8560$

$K = \frac{8560}{\cancel{107}} \times \frac{1.21}{4 \times .59}$

$K = \underline{2.59}$



910		1022	55
910		1010	68
940		1008	70
978		1011	67
1022		1006	72
1040		1001	77
1069		987	91
1074		985	93
1078	0	985	93
1069	9	980	98
1072	6	975	103
1070	8	969	109
1061	17	962	116
1049	29	951	127
1052	26	949	121
1041	37	942	136
[illegible]8	40	[illegible]8	140
1033	45	128	150
1035	43	118	160
1031	47	[illegible]	178
1030	48		

[illegible]		1000		
[illegible]		1000		
[illegible]		1030		
300		1080		
[illegible]		1126		
[illegible]		1145		
[illegible]		1178		
[illegible]		1189		
[illegible]		1200	0	
[illegible]		1199	1	
[illegible]		[illegible]8	12	120
[illegible]		1182	18	164
[illegible]		1180	20	167
[illegible]		1178	22	169
[illegible]		1165	35	250
[illegible]		1163	37	247
[illegible]		1163	37	231
[illegible]		1163	37	218
[illegible]		1160	40	222
[illegible]		1158	42	221
[illegible]		1150	50	250

[illegible]		1148	52	248
[illegible]		1148	52	236
[illegible]		1142	58	252
[illegible]		1142	58	242
[illegible]		1140	60	240
[illegible]		1136	65	250
2700		1132	68	252
[illegible]		1132	68	243
[illegible]		1122	78	269
[illegible]		1112	88	293
[illegible]		1111	89	287
[illegible]		1111	89	278
[illegible]		1110	90	273
[illegible]		1106	94	270
[illegible]		1100	100	285
[illegible]		1098	102	284
[illegible]		1090	110	277
[illegible]		1088	112	275
[illegible]		1072	128	328
[illegible]		1070	130	325

P	%P	B	ΔB	[illegible]	[illegible]
0		1030			
100		1018			
200		1050			
300		1100			
400		1137			
500		1170			
600		1191			
700		1208			
800		1211	0		
900		1210	1		
1000		1208	3	30	
1100		1199	12	109	
1200		1200	11	11.6	
1300		1188	23	177	
1400		1192	19	136	
1500		1189	22	147	
1600		1190	21	131	
1700		1180	31	182	
1800		1182	29	161	
1900		1178	33	174	
2000		1162	49	245	

TIME TIME TIME

1170/1633 1162/ 1175/1641

P	%P	D	ΔB	[illegible]	%ΔB		TIME
2100		1175	36	171			
2200		1165	46	209			
2300		1165	46	200			
2400		1155	56	233			
2500		[illegible]	56	224			
2600		1151	60	231			
2700		1154	57	211			
2800		1154	57	204			
2900		1159	53	183			
3000		1152	59	197			
3100		1154	57	184			
3200		1151	60	188			
3300		1152	59	179			
3400		1147	64	188			
3500		1140	71	203			
3600		1141	70	194			
3700		1131	80	216			
3800		1122	89	234			
3900		1115	95	244			
4000		1109	102	255			1628

NN

SHEET 14 RUN 3

1.5"

$$P_{cr} = \frac{\delta \Delta B}{\delta \frac{\Delta B}{P}} \times 10^{4} = \frac{60}{250 - 75} = \frac{60}{175} = 3430 \text{ LBS}$$

$$\sigma_{cr} = \frac{3430}{.102 \times 16} = 10710$$

$$K = \frac{\sigma_{cr}}{E} \cdot \left(\frac{d}{t}\right)^2$$

$$= \frac{10{,}710}{10^7} \times \frac{2.25}{4 \times 10^{-4}}$$

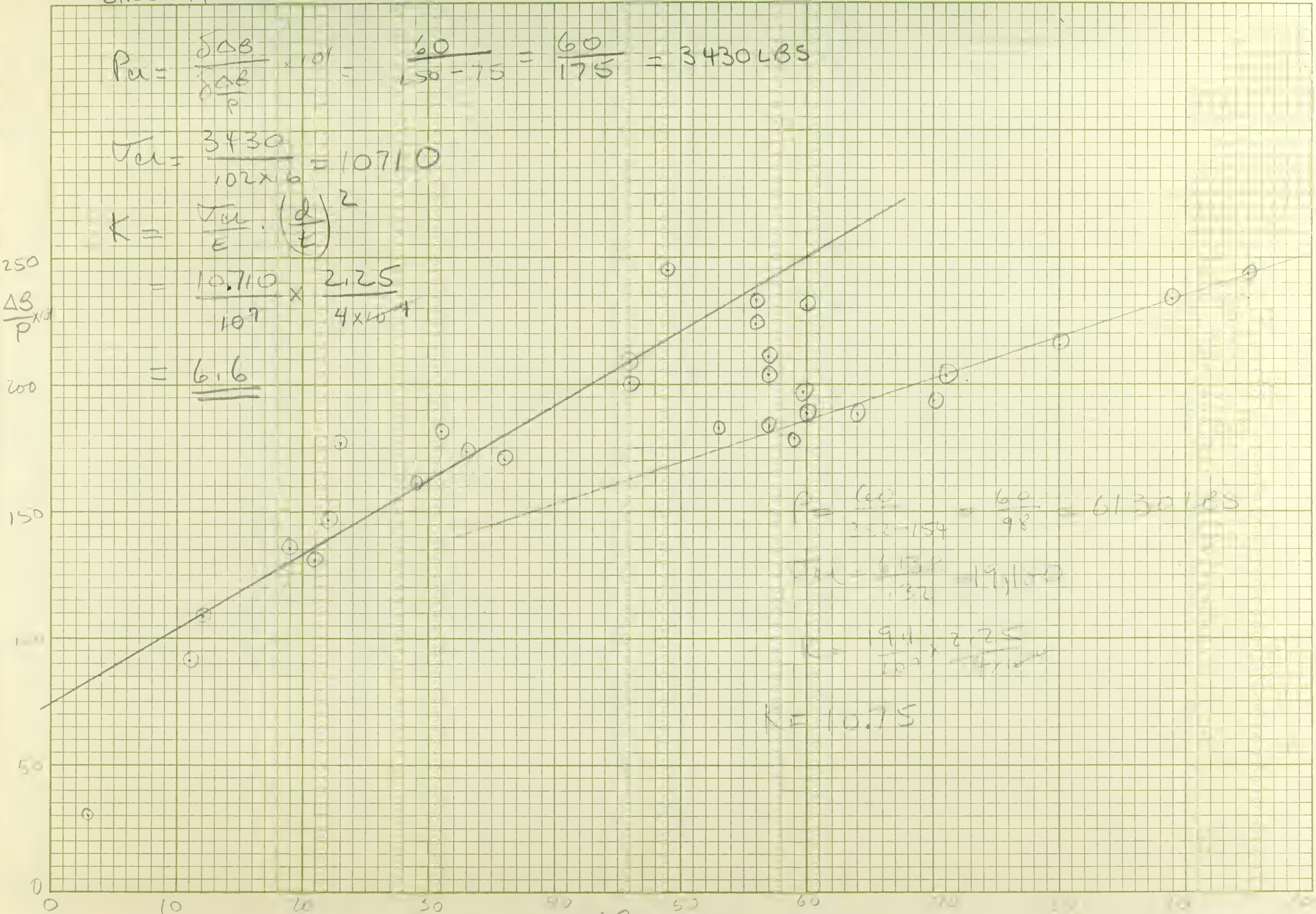
$$= \underline{\underline{6.6}}$$

$$P = \frac{60}{252 - 154} = \frac{60}{98} = 6130 \text{ LBS}$$

$$\sigma_{cr} = \frac{6130}{.32} = 19{,}150$$

$$K = \frac{194}{10^7} \times \frac{2.25}{4 \times 10^{-4}}$$

$$K = 10.75$$



NN

P	L^{10}/P	B	ΔB corrected for meter drift	$\frac{\Delta B}{P} \times 10^4$
0		1065		
100		1060		
200		1092		
300		1135		
400		1175		
500		1205	17	340
600		1225		
700		1232		
800		1238		
900		1232		
1000		1230	33	330
1100		1230		
1200		1222		
1300		1218		
1400		1215		
1500		1205	48	320
1600		1202		
1700		1200		
1800		1160		
1900		1192		
2000		1190	65	325
2100		1190		

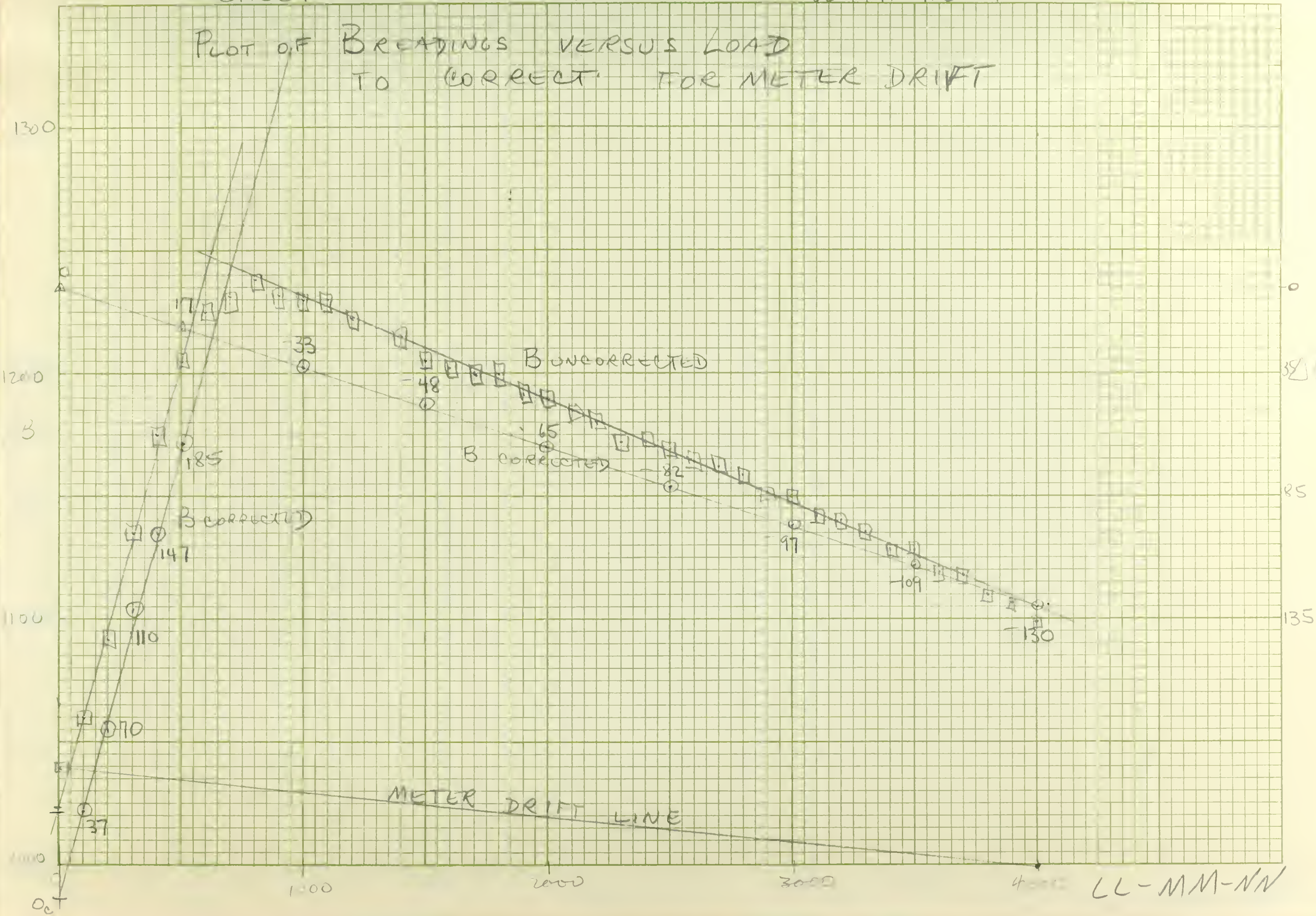
P		B	ΔB corrected for meter drift	
2100		1185		
2200		1180		
2300		1172		
2400		1172		
2500		1169	82	328
2600		1164		
2700		1162		
2800		1159		
2900		1151		
3000		1150	97	323
3100		1142		
3200		1140		
3300		1136		
3400		1128		
3500		1128	109	311
3600		1119		
3700		1118		
3800		1110		
3900		1107		
4000		1099	130	325

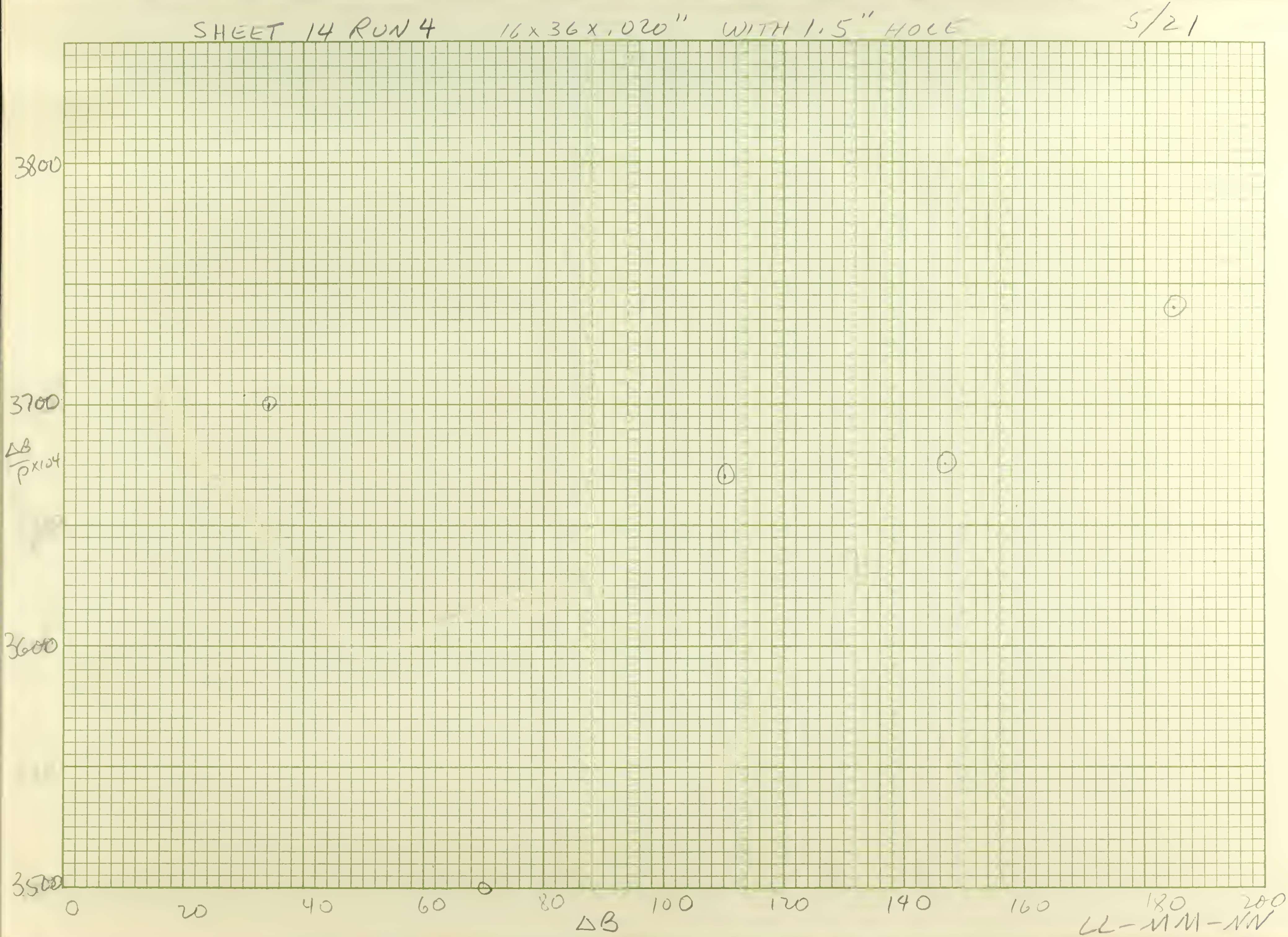
LL-MM-NN

P	/P	CORRECTED	/P	/ΔB
0		0		
100		37	3700	
200		70	3500	
300		110	3670	
400		147	3675	
500		185	3740	
600				
700				
800				
900				
1000				
1100				

LL-MM-NN

SHEET 14 RUN 4 16 x 36 x .020" WITH 1.5" HOLE




SHEET 14 RUN 4 16 x 36 x .020" WITH 1.5" HOLE
5/21
3800
3700
$\frac{\Delta B}{\rho} \times 10^4$
3600
3500
0
20
40
60
80
100
120
140
160
180
200
ΔB
LL-MM-NN

Thesis 35703
D155 Danis
An investigation of the buckling caused by compressive forces existing in a thin elastic sheet.